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FACTORS AFFECTING THE ADOPTION OF R&D PROJECT SELECTION TECHNIQUES AT THE AIR FORCE WRIGHT AERONAUTICAL LABORATORIES

THESIS

Jonathan D. Congdon, Capt, USAF

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THESIS

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Jonathan D. Congdon

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Jonathan D. Congdon

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Abstract

Although several techniques have been developed to enhance R&D project selection decision-making in research laboratories, they have not been widely accepted by managers. This research investigated three aspects relating to the implementation of R&D project selection techniques at the Air Force Wright Aeronautical Laboratories (AFWAL). It examined 1) the methods used by managers to make R&D project selection decisions; 2) the attitudes and perceptions of managers toward the utility of R&D project selection techniques; and 3) the specific factors affecting the adoption of these techniques by R&D managers.

Findings showed that formal R&D project selection techniques play a minor role in the project selection process, and that managers are, in general, unfamiliar with a majority of these techniques. It was found that project selection decisions are made by a "corporate board" consisting of top-level managers. The respondents indicated that they were generally satisfied with this process despite feeling a moderate amount of pressure to quantitatively justify their resource expenditures. Findings also showed that the R&D project selection process at AFWAL is heavily influenced by "requirements pull" as opposed to "technology push."

Factor analysis was used to identify an initial set of variables which affect management's willingness to adopt formal project selection techniques. Nine variables were found to affect management's "willingness to adopt." These variables were factored into two groups which relate to 1) the effect of project selection techniques on organizational decision-making; and 2) the characteristics of the project selection techniques themselves. The results showed that the respondents possessed negative perceptions toward the utility of these techniques as a management tool.

Previous research efforts have shown that negative-to-positive attitude shifts occurred after respondents were educated and trained in the use of these techniques. Consequently, it was recommended that the respondents be provided with training to increase their understanding of these techniques. Once accomplished, a follow-up survey should be administered to assess the stability of the initial set of adoption-affecting variables, and the results used as a guide to select or develop project selection techniques which would be accepted and implemented as a management tool.

FACTORS AFFECTING THE ADOPTION OF R&D PROJECT SELECTION TECHNIQUES AT THE AIR FORCE WRIGHT AERONAUTICAL LABORATORIES

I. Introduction

Background

Within the Air Force, the continued advancement and expansion of technological capabilities is the responsibility of a network of research and development (R&D) laboratories operating under the direction of the Air Force Systems Command. This network of laboratories is the focal point for the planning and execution of basic research, exploratory and advanced development, selected engineering development, and assigned manufacturing technology programs (32:2). The R&D manager in this environment is responsible for evaluating, selecting, and funding research projects which exhibit a high potential for achieving technical success. This process of R&D project selection and resource allocation has been called "the key to research success" (33:169).

In an effort to improve the effectiveness of this decision-making process, several formal project selection techniques have been developed. Ranging from scoring models to linear programming, these techniques are, for the most part, derived from applications of management science and operations research (MS/OR) (15:16).

Ideally, these project selection techniques offer the R&D manager a systematic method for assessing the potential value of research projects, thereby improving managerial decision making. However, surveys of both private and public sector research institutes indicate that R&D managers are reluctant to adopt these techniques (23:962; 31:40). Methods to increase the adoption of MS/OR as a management tool have been the subject of focused research since the early 1970s (39:xiii).

Management's reluctance toward the use of MS/OR is not unique to the R&D environment. The implementation of quantitative techniques has been found to be quite low for many potential applications (40:3). Surprisingly, this reluctance on the part of managers has persisted, despite increased exposure to MS/OR in academia, and the development of user-friendly software for project management (23:963). Randall Schultz and Dennis Slevin have expressed concern about this trend, noting that:

> The ultimate question that can be asked of management science is whether or not it has had an impact on decision making in organizations. The question involves management science implementation, the bridging of the gap between theory and practice, and the improvement of organizational effectiveness through organizational change. (40:1)

Justification

In "Our Tech Base Needs Attention," General Robert Marsh underscores the importance of maintaining U.S. technical

superiority to counter Soviet military challenges. According to General Marsh,

> if we seek to maintain our security without having to pay the prohibitive price of matching the Soviet Union in sheer numbers, then we must resolve to adequately support the research and development necessary to stay ahead technologically. (28:90)

General Marsh notes that an unfavorable trend is developing in the balance between U.S. and Soviet technological development which is "a direct result of diminished U.S. support for military R&D" (28:91). Thus, in the future, the military R&D manager will be faced with the challenge of reversing this trend with a constrained research budget. As such, it will be of paramount importance that laboratory resources are used as effectively and efficiently as possible. Unfortunately, the implementation of techniques designed to enhance R&D project selection decision making has been found to be a difficult and complex process.

In Management - A Quantitative Perspective, N. Paul Loomba examines the nature of the implementation problem:

> The implementation of quantitative models is an extremely complex area. It involves multifaceted relationships and interactions among the manager, management scientist, top administration, production personnel, and other organizational resources (e.g. computer systems). (25:457)

Thus, the goal of the implementation researcher is to gain an understanding of the attitudes, perceptions, and requirements of managers concerning MS/OR techniques. With this information, MS/OR professionals can develop techniques

that are responsive to the needs of managers, thus increasing their acceptance by organizations.

By 1968 it was recognized that there was a need for a mutual understanding between those who develop MS/OR techniques - the management scientists - and the managers who may utilize these techniques. Thad Green notes that progress in this area has been slow:

> More than a decade has passed and there is little progress toward a mutual understanding. This is due to the very nature of the situation. Managers who do not see the value in using decision science models are reluctant to use them. Yet, until managers use the models, they likely will not perceive them as having much value. Thus we are in a vicious cycle. (14:6)

The need for continued implementation research is readily apparent. In a review of implementation literature, Schultz and Slevin concluded that 1) there has been an insufficient amount of research in the area; and 2) what has been done is theoretical in nature, as opposed to empirical (38:153).

> Although theoretical discussions are a necessary and integral part of the development of any field of research, at some point in time, they must be examined for their conformity with empirical evidence. (38:153)

Applications in the R&D Environment

While it may appear that R&D managers would be receptive to the "scientific method" upon which formal, sophisticated project selection techniques are based, the evidence does not support this assumption. A 1983 industry survey of 40 laboratory managers from 29 Fortune 500 companies concluded

that there was "heavy use of financial methods of project selection, but virtually no use of math programming for R&D resource allocation" (23:962).

In addition, a 1985 survey of managers at the Air Force Wright Aeronautical Laboratories (AFWAL) found that only 30 percent of the respondents reported using a formal project selection technique (31:40). Dr. William Souder notes that

> this lack of usage may be a consequence of the lack of attention which model builders have traditionally given to the prevailing adoption attitudes of R&D managers. (45:75)

A comparison of the R&D environments in both the public and private sectors sheds additional light on the implementation problem.

Whereas private sector R&D is primarily concerned with profit maximization, the goal of military R&D is to enhance our ability to meet mission requirements. The complexities of the military mission and the focus of military research on operational enhancement places unique constraints on the military R&D manager. Unfortunately, many of the project selection techniques which are designed to assist managers in the selection of research projects were developed for the private sector, and with their objective of profit maximization in mind. This makes their utility questionable in the context of public sector R&D (36:126).

In addition, there are many organizational differences between the public and private sectors. In "The Future of Operations Research in the Government," Thomas Saaty offers

this explanation for the apparent resistance within the government toward the use of MS/OR techniques:

> Departments of the government are rarely in competition for survival, though their leaders may come under political fire. For their structure, they rely on a long tradition of operation. It is natural that they tend to resist change to maintain their identity. Sometimes rivalry and power plays lead to rigidity. Undoing these rigid forms is a slow process. Industry operates in a competitive environment. To survive, it must be flexible. (37:6)

Despite these difficulties, there are some examples of successful implementations of quantitative project selection techniques in government research agencies. The Division of Power Systems of the Department of Energy researched formal project selection techniques in 1978 and subsequently adopted a scoring model to assist in the selection of applied R&D projects (3:1). In addition, new advances in formal project selection techniques appear to offer the military R&D manager a rational, systematic method for assessing research projects and allocating resources. Souder notes the following:

> The naive modelling application philosophies of the 1950s and 1960s have grudgingly given way to a more mature, modern philosophy. Both managers and model builders should be aware of this philosophy and its potential for importing decisions about project selection. (46:36)

General Issue

The focus of this research is the R&D project selection process at the Air Force Wright Aeronautical Laboratories (AFWAL) located at Wright-Patterson Air Force Base. AFWAL consists of the Aero Propulsion Laboratory, the Avionics

Laboratory, the Flight Dynamics Laboratory, and the Materials Laboratory. Together, these four laboratories have an annual operating budget in excess of $850 million, and they employ over 1700 scientists. AFWAL is one of the largest research and development complexes in the free world (32:2).

This research will investigate the R&D project selection process at AFWAL. It will focus on 1) the methods used by AFWAL managers to select R&D projects and allocate laboratory resources; 2) the attitudes and perceptions of AFWAL managers toward the utility of R&D project selection techniques; and 3) the specific factors that affect management's willingness to adopt these techniques.

The results of this research will provide valuable insight into the R&D project selection process and organizational climate at AFWAL. By measuring management's perceptions toward the utility of formal project selection techniques, and subsequently deriving a set of adoption-affecting variables, a basis is formed from which to evaluate project selection techniques and identify those which are compatible with the organization (44:133; 45:75).

Research Questions

The following research questions will be used to guide this investigation:

1. What methods do managers use to select R&D projects and allocate laboratory resources at the Air Force Wright Aeronautical Laboratories?

2. What are the attitudes and perceptions of managers toward the use of formal R&D project selection techniques?

3. What factors affect management's willingness to adopt formal R&D project selection techniques?

Scope and Limitations

This research focused primarily on AFWAL as a single organization. However, whenever possible, significant differences between the individual laboratories which comprise AFWAL were noted.

While there are several other laboratories operating under the direction of the Air Force Systems Command, time and travel constraints made it impractical to examine these facilities.

Terms and Definitions

For the purpose of this research, the following terms and operational definitions will be used:

R&D project selection techniques. "A formal, often quantitative model or algorithm employed to assign values to individual R&D projects or groups of projects" (36:124). For this research, the terms "project selection technique," "formal technique," "project selection model," "quantitative technique," and "formal decision method" are synonymous.

Implementation. The involvement of a formal project selection technique to aid the process of evaluating competing R&D projects and allocating resources (40:6).

Management science/operations research (MS/OR). A branch of the field of management which employs a rational, logical, systematic, and scientific approach to analyze the process of management and management problems (25:18). For the purpose of this research, the terms "management science," "operations research," "decision sciences," "system sciences," and "systems analysis" will be used interchangeably.

Chapter Summary

This chapter provided an introduction to, and motivation for this research effort. It began with a discussion of the implementation of MS/OR and R&D project selection techniques in organizations. Next, the need for empirical research in this area was established. This was followed by an overview of the R&D environment in both the public and private sector. Finally, the research questions that guided this effort were presented, along with a series of key definitions. The following chapter provides a review of applicable literature.

II. Literature Review

Introduction

This literature review examines three major topic areas. In the first section, Implementation Research, a working definition of implementation is provided, as well as a review of the origins of MS/OR as a management tool. The remainder of the section is devoted to a review of several prominent implementation research efforts. The research efforts included in this review were selected for their contribution to the identification of factors affecting the implementation of MS/OR based techniques in a variety of organizations.

The second section, The Implementation of R&D Project Selection Techniques, is more narrowly focused, and specifically examines the implementation of R&D project selection techniques. This section includes a discussion of the barriers that often preclude the use of formal R&D project selection techniques. It also includes a comparison of R&D management in the public and private sectors.

The third section, R&D Project Selection Techniques, examines four categories of R&D project selection techniques. This section provides a review of each category's capabilities, strengths, and weaknesses.

Implementation Research

Implementation Defined. A wide variety of definitions are used throughout the literature to describe the implementation of MS/OR in organizations. This research is best

served by the "behavioral perspective of implementation" proposed by Schultz and Slevin (40:3). Schultz and Slevin note that there are three major participants in the implementation process: MS/OR professionals, middle management, and top management. The definition developed by Schultz and Slevin considers the perspective of each of these participants.

The perspective of the MS/OR professional is that if a technique works, and is technically valid, it is successful. On the other hand, middle managers take the point of view that a technique is successful only if it is used and maintained by the organization. Finally, top management requires not only that a MS/OR technique is used and maintained, but that it influences decision making in a way that benefits the organization (40:3). To fully define implementation in the context of the organization, all three perspectives must be integrated. According to Schultz and Slevin,

> the behavioral perspective of implementation includes the development (technical validity) and the use (organizational validity) of a model or technique that results in a positive change in organizational effectiveness (positive top management evaluation). (40:4)

A Historical Perspective. MS/OR emerged during World War II, and rapidly gained in popularity. From this time, until the mid-1960s, MS/OR was seen as a new and effective management tool. Its use was widely accepted and encouraged by many top managers in both industry and government. However, in the years following, some MS/OR applications did not live up to expectations. Subsequently, top management

acceptance of MS/OR began to decline. This prompted several research efforts to determine its causes (40:5).

Current Research Efforts. In 1973, a conference entitled "The Implementation of OR/MS Models: Theory, Research, and Application" was held in Pittsburgh, Pennsylvania. Its purpose was to review previous implementation research and "identify avenues that will lead to a better utilization of MS/OR as a true problem-solving activity" (39:xiii). This conference served to consolidate and focus implementation research efforts.

Since 1973, there has been a significant increase in implementation research efforts. Several of the most prominent research efforts of the past 15 years have been compiled into three major works entitled Implementing Operations Research/Management Science, published in 1975, The Implementation of Management Science, published in 1979, and Applications of Management Science, published in 1984. Though these compiled works represent three distinct "generations" of implementation research, they each emphasize the behavioral aspects of the implementation process (41:x).

> The principal reason for this reliance on behavioral methodologies is the fundamental nature of the implementation problem. It is, in any interpretation, a problem involving human participants, social interaction, organizational structure, and management change - in short, a complex behavioral process. (40:8)

The First Generation. The first generation of implementation research can be characterized as an effort to model the implementation process in organizations (42:63).

These research efforts often resulted in the identification of variables which were found to influence the implementation of MS/OR techniques in organizations.

The research conducted by Souder, and presented in "An Organizational Intervention Approach to the Design and Implementation of R&D Project Selection Models," provided the framework for this effort (44; 45). Souder's research methodology is described below.

> The methodology consists of procedures for analyzing the organizational climate relative to project selection model usage, developing an acceptable model form relative to the organization, and inducing the adoption of this model form. (45:75)

To facilitate this research, Souder developed a Likert-based survey instrument designed to test several variables which were thought to influence a manager's willingness to adopt R&D project selection techniques. Using correlation techniques, Souder found that the adoption-affecting variables could be grouped into three factors; these factors are "model characteristics," "organizational factors," and "personal decision variables" (44:139). Figure 1 depicts the variables, and how they were grouped into the factors described above. The adoption-affecting variable set was then used as an input to develop a "linear discriminant function to evaluate and rate the acceptability or adoption potential" of a variety of project selection techniques (45:79).

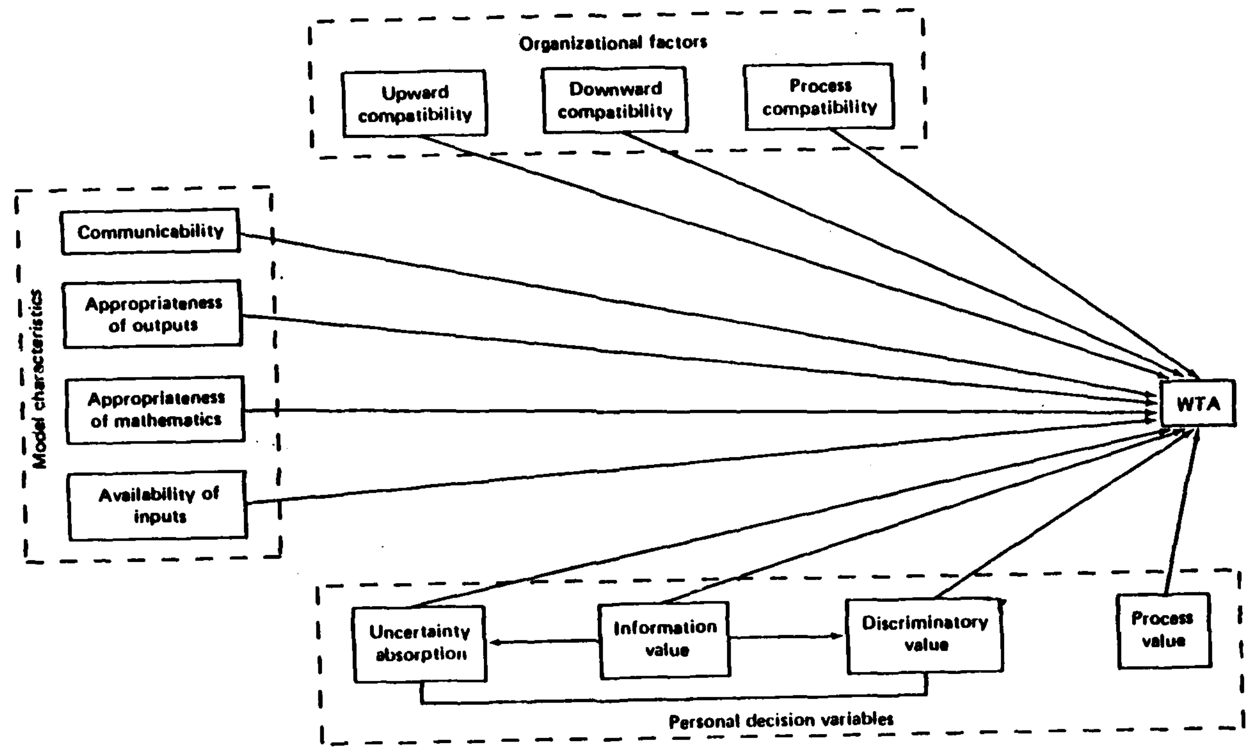

Figure 1. Souder's Adoption-Affecting Variables and Factors Adapted from (44:139)

To ensure that the variables used to evaluate and rate potential techniques accurately represented the views of the respondents, Souder employed a longitudinal research approach. First, a survey was administered to each respondent to obtain an adoption-affecting variables set. Next, a training session was provided to the respondents which covered the potential applications of R&D project selection techniques. Following the training session, the survey was re-administered, and the resulting set of adoption-affecting variables was compared to the original set. Souder maintains that "a stable set of variables will be indicated when two successively administered questionnaires do not differ statistically" (45:79). Souder's longitudinal approach served two purposes. Not only did it derive a stable set of adoption-affecting variables, but it also demonstrated the effect that information and training had on the perceptions and attitudes of the respondents. In applications of this research, Souder observed a "negative-to-positive shift in adoption attitudes," indicating that the lack of understanding of the capabilities of R&D project selection techniques has a significant influence on their adoption by management.

Schultz and Slevin have also made significant contributions to implementation research. One of their more noteworthy efforts is described in "Implementation and Organizational Validity: An Empirical Investigation" (38:153). In this effort, the researchers sought to

determine the key factors which affect the successful implementation of MS/OR in organizations. The researchers found that the respondents' attitudes toward the implementation of MS/OR techniques were dependent upon several factors. These factor are summarized in Table 1.

Table 1.

Schultz and Slevin's Factors
Affecting Implementation Success

1. Effect on job performance
2. Effect on interpersonal relationships
3. Extent of organizational change
4. Effect on organizational goals
5. Degree of top management support
6. Implementor and manager relations
7. The urgency and need for an MS/OR technique

Adapted from (38:153)

The research conducted by John Manley has also contributed significantly to the identification of adoption-affecting variables. Manley focused on the measurement of external variables associated with MS/OR implementation.

In Manley's experiment, the subjects were given nearly identical descriptions of an MS/OR model. However, one of the key variables shown in Table 2 was changed in each new description. From these responses, Manley measured the group's resistance to, or support of the MS/OR model, in

terms of the five key variables (26:190). These variables are shown in Table 2.

Table 2.

Manley's External Variables
Affecting MS/OR Implementation

1. The level of chief executive support for the MS/OR product.
2. The priority level assigned to the implementation project by management.
3. The degree of product relevancy to the client's organizational role.
4. The level of required client involvement to implement the product
5. The complexity of the MS/OR product.

Adapted from (26:190)

Several research efforts conducted at Northwestern University under the direction of Michael Radnor have also provided a significant contribution to the field of implementation research. Table 3 shows the variables which were found by Radnor and the researchers at Northwestern University to influence the implementation of MS/OR in organizations.

Gary Powell's work also enhanced implementation research considerably. In his efforts, Powell maintained that the failure of MS/OR in organizations was due to the lack of consideration of "human variables" in the model-building process (30:88). Powell suggests that

> the strong research orientation of MS/OR has led to many projects being conducted without concern for

whether the results will ever be implemented in an organizational setting. As a result, we have more sophisticated technical models without the improved sophistication needed to implement them. It is evident that problems of OR/MS implementation may be alleviated by more attention being paid to human variables in research projects and to the relationship with the client. (30:88)

Table 3.

Radnor's Variables Affecting MS/OR Implementation (circa 1970)

1.	Recognition of the need for an MS/OR technique
2.	Willingness of the individuals in the receiving unit to interrupt ongoing work
3.	Technical mismatch in understanding of the specifications of the item
4.	Mismatch in understanding of the objectives of the project or task
5.	Pre-existing relationships of trust between the parties to an implementation transaction
6.	Degree of managerial involvement in the stages of a project
7.	Self-interest
8.	Urgency
9.	Perceived threat
10.	Level of managerial support
11.	Point in time at which a management commitment is made to the project

Adapted from (35:971)

In his research, Powell found that the six variables shown in Table 4 were the keys to determining success or failure of MS/OR implementation.

Table 4.

Powell's Variables Affecting MS/OR Implementation

1.	The environmental context of the organization
2.	The goals and norms of the organization itself
3.	The relationship between the organization and the OR/MS implementation group
4.	The conduct and selection of projects
5.	The individuals involved
6.	The relationship between managers and operations researchers

Adapted from (30:84)

<u>The Second Generation</u>. Whereas the first generation of implementation research was characterized by efforts to model the implementation process, the second generation was noted for its focus on empirical research in an effort to validate the previous models of the implementation process (42:62).

Of particular significance to this research is the institutional analysis approach taken by Radnor. In "The Context of OR/MS Implementation," Radnor found that the weakness of much of the existing implementation research is its reliance on "narrowly defined OR/MS practitioner/client relationship models" (34:17). According to Radnor,

> the literature has generally stopped with expressions of philosophy or descriptions of effects, and thus fails to provide tools or approaches which could help MS/OR practitioners deal with their real life implementation problems. (34:18)

Radnor recommended future research which would consider a broader contextual approach. According to Radnor, implementation research must consider "the totality of all factors and dynamics and their interaction which impact OR/MS implementation" (34:18). Radnor notes that

> this approach suggests a rich, descriptive taxonomy of variables and an analytical methodology which will allow OR/MS implementation research to focus on the OR/MS implementation context, thereby stimulating and assisting in the building of richer and more realistic models. (34:18)

Radnor contends that the contextual dimensions shown in Table 5 have a critical effect on MS/OR implementation.

Table 5.

Radnor's Contextual Dimensions Affecting MS/OR Implementation (circa 1979)

1.	OR/MS programs: projects and portfolios
2.	OR/MS as a change phenomenon
3.	Environment
4.	Organization
5.	Operations (technology)
6.	Management
7.	Resources

Adapted from (34:18)

Radnor provides a "checklist" of factors to be considered under each of the seven contextual dimensions listed above, and suggests the use of a matrix format for individually addressing each dimension. In total, Radnor lists

over one hundred individual factors which can affect the implementation of an MS/OR project (34:22-32).

The Third Generation. The third generation of implementation research begins with the works found in Applications of Management Science (41:ix). The editors of this work suggest that implementation research can be categorized into three groups: factor research, cognitive research, and process research (41:x). The authors note that factor research focuses on "the characteristics of the organization, problem, technology, and people involved" (41:x). The second group, cognitive research, considers the "differences in cognitive styles between system users and builders" (41:x). Finally, process research focuses on the characteristics common to successful implementations (41:x).

With respect to the research performed in previous "generations" Randall Schultz and Michael Ginzberg note the following:

> The models used to guide first and second generation implementation research are, in general, quite simple. Thus they have only limited ability to provide insight into the implementation problem. Further progress in implementation research will require more complex, realistic models and the development of alternative perspectives for viewing implementation. (41:xi)

The need for a new direction in future research efforts is shared by several researchers. In "A Reassessment of Implementation Process Models," Ananth Srinivasan and Joseph Davis conclude that both the wide diversity of users and the rapid changes in OR/MS and management information systems

technologies has "eroded" the relevance of efforts to model the implementation process (47:64). They note that since quantitative management techniques can be implemented on personal computer systems, the traditional models of implementation which typically involved large main-frame systems, are no longer useful in describing the new decision-support environment (47:69).

In "Beyond the Model," Geoff Lockett also notes that implementation research itself "is in a state of transition" as micro-computers, artificial intelligence, and management information systems become increasingly more prevalent in organizations (24:174). Lockett notes that "managers live in an environment which is unusually turbulent. Much of their work is spent fire-fighting with little time for calm decision making" (24:175).

Lockett maintains that the traditional role of the systems analyst "has become blurred" as a result of rapidly changing OR/MS and management information system technologies, and he recommends that future implementation research efforts consider this (24:175).

This section has provided an overview of some of the major implementation research efforts of the past 15 years. The remainder of this literature review will focus specifically on the potential applications of formal R&D project selection techniques as a means to enhance the effectiveness of R&D project selection and resource allocation decisions.

The Implementation of R&D Project Selection Techniques

In "The Practice of Management Science in R&D Management," Matthew Liberatore describes the R&D project selection process as

> the allocation of scarce organizational resources, namely, funds, manpower, and facilities, to a set of proposals for scientific and engineering activities. (22:12)

Consequently, one of the most important tasks facing the R&D manager is to select the most promising research projects in order to use resources effectively.

Although technological developments have advanced tremendously in the past 50 years, the process by which R&D projects are selected has not. Lowell Steele compared today's project selection process to that of the 1930s, and made the following observation:

> Examining the management of industrial R&D over the past 50 years leaves an intriguing impression: a member of a laboratory of the 1930s would feel quite comfortable with the way a laboratory of the 1980s defines its purposes and decides what programs to pursue. He would be surprised at the wealth of information that has to be evaluated, at the number of people involved in the process, and at much of the management terminology. But most important, he would not be surprised at the extent to which informed managerial judgment still plays the decisive role in selecting programs. (48:21)

In the forward to Management of Research and Innovation, Jordan Baruch notes that until now, most R&D managers felt that technological innovation "was something that befell a firm, not something for which one planned" (6:vii). An examination of the R&D environment provides some insight into this problem.

According to James Matheson, "uncertainty, complexity, and long lead times are fundamental characteristics of research and development" (29:329). Steele substantiates this opinion with his description of R&D management in the 1980s. First, he notes that there is a "great diversity in management practice" (48:23). In spite of the emergence of numerous quantitative project selection techniques, no one technique is widely accepted as the standard. Second, Steele notes an ambivalence on the part of managers toward the use of formal project selection techniques. In describing the effect that formal techniques have on the R&D project selection process, Steele concludes that "they might as well have not been developed (48:23). Steele also maintains that while scientists and engineers tend to seek quantitative approaches to problems

> their appreciation of the complexities and subtleties of project selection and of the severe limitations on the utility of those techniques that have been developed make managers exceedingly reluctant to give them a dominant role in the process. (48:21)

Despite the limited use of formal project selection techniques, Steele notes that close attention is given to the process of R&D project selection (48:23). This is primarily because of the "increasingly stringent demands for performance" facing today's R&D manager (48:20).

Despite increasing demands for more effective use of resources, most R&D managers select their research projects through an organizational review process:

> Typically these reviews include an examination of progress in the recent past; a delineation of the most important problems to be addressed in the next phase; consideration of the human, financial, and other resource requirements needed for optimum progress; analysis of the competitive and patent status of the program; evaluation of its potential benefit and the importance of timing; and finally, consideration of the capability and desire of the company to commercialize the development. (48:28)

Steele concludes his article with several observations.

First, despite the limited impact that quantitative techniques have had on the project selection process, the increasing scale and complexity of the R&D environment has forced managers to seek out formal procedures for project selection.

Second, quantitative projection techniques "evoke a love-hate attitude among researchers" (48:33). Steele notes that "intellectual bent encourages their use, while wariness of their limitations fosters caution" (48:33).

Third, Steele notes that "the demands on managerial time and limitations on availability of quantified inputs" are the primary reasons for the limited use of project selection techniques (48:34).

Finally, Steele feels that "managerial judgment is in no danger of being replaced as the ultimate umpire" in project selection decisions (48:34).

Barriers to Implementation. Several researchers have sought to determine the reasons that MS/OR techniques are often resisted by managers.

Ivan Vertinsky suggests that the limited use of MS/OR techniques is due to 1) the perception among managers that MS/OR is a threat to their security; 2) the misunderstanding of the capabilities of MS/OR, especially among older personnel; and 3) the reliance on "traditional, crisis-oriented management" (49:255).

C. Jackson Grayson notes that managers often reject MS/OR techniques due to 1) shortage of managerial time; 2) inaccessibility of input data; 3) resistance to change, 4) the slow response time of many MS/OR models, and 5) over-simplified models (13:25-27).

In a more detailed examination of R&D project selection techniques, E. P. Winkofsky concluded that many of these techniques possess several limitations. Winkofsky's conclusions are summarized in Table 6.

In "A System for Using R&D Project Evaluation Methods," Souder attempts to isolate the reasons why quantitative project selection techniques are often ignored by R&D managers. He maintains that many of the older quantitative techniques are not widely accepted because of their failure to accurately reflect the project selection process. Souder found that many quantitative models consider only the analytical aspects of project selection, and fail to consider the impact that "organizational and human behavior" have on the project selection process. He therefore suggests that before a quantitative technique can be useful to an R&D manager, organizational goals and objectives must be agreed

Table 6.

Winkofsky's Limitations of R&D Project Selection Techniques

1.	Inadequate treatment of multiple, often interrelated criteria
2.	Inadequate treatment of project interrelationships with respect to value contribution and to resource utilization
3.	No explicit recognition and incorporation of the experience and knowledge of the R&D manager
4.	The inability to recognize and treat non-monetary aspects such as establishing and maintaining balance in the R&D program
5.	Perceptions held by the R&D managers that the models are unnecessarily difficult to understand and use
6.	Inadequate treatment of the time variant property of data and selection criteria

Adapted from (50:191)

upon, there must be a feeling of trust among workers, and all involved parties must have an in-depth knowledge of the projects being considered (43:33-34).

The focus on organizational dynamics and differences by many implementation researchers prompted a comparison between R&D in the public and private sectors. The following section explores the similarities and differences between R&D management in these two environments.

Public and Private Sector R&D. The literature comparing R&D in the public and private sectors indicates that there may be significant differences between R&D project selection in the public and private sectors, and that this may have an

effect on the applicability of quantitative project selection techniques.

In "The Multiple Functions of Formal Aids to Decision Making in Public Agencies," J. David Roessner noted that "R&D project selection decisions in public agencies must incorporate a much wider range of criteria than equivalent decisions in private firms" (36:128). However, Roessner suggests that quantitative techniques can be effective in public sector project selection to "screen candidate projects, to help structure the allocation problem, and to help make the allocation project more systematic" (36:127).

Frederick Betz also examined the differences between R&D in the public and private sectors, concluding that:

> In the process of contracting out R&D, the manager in government is constrained in the project selection process by political and participatory considerations and legalistic regulation. (2:236)

Because a significant portion of government R&D is performed under contract (up to 71% in the DoD), Betz maintains that "only in managing intramural federal R&D does the public sector R&D manager closely resemble his private sector counterpart" (2:236). Betz also notes that

> as government research moves in the R&D spectrum from basic and applied research to development, then the governmental R&D manager's selection of projects begins to look more similar to the industrial manager's concerns. (2:236)

Radnor found that government organizations generally have less well-defined outputs and goals than does business

and thus "we could then expect implementation problems of a differing order of magnitude" (35:977).

K. G. Feller reviewed methods for evaluating R&D project selection techniques for the U.S. Department of Energy's Office of Advanced Conservation Technologies. He found that the assumptions on which many project selection models are based are often inappropriate when applied to government R&D programs. Speaking of formal project selection methods, Feller maintains that

> 1) The methods imply centralized planning and centralized authority to take the necessary actions over the time needed to develop and implement a technology;
>
> 2) The methods imply an easily agreed-upon measure of merit; and
>
> 3) The methods imply a readily-available source of high-quality information about the R&D objects, the application of the subject technology, and the market for the product being developed. (10:4)

There appears to be substantial differences in the management of R&D in the public and private sectors. Bearing in mind these differences, this research will investigate the R&D project selection process at the Air Force Wright Aeronautical Laboratories, in a effort to understand the organizational climate and the applicability of formal project selection techniques.

R&D Project Selection Techniques

This final section examines the range of R&D selection models available to laboratory managers.

A formal R&D project selection technique is a quantitative method used to assign values to individual R&D projects or groups of projects (36:124). Models which are used to evaluate individual research projects are known as project selection models (15:16). Models which are used to evaluate a combination of interrelated research efforts are known as portfolio selection models (16:21). It is estimated that "literally thousands of project and portfolio selection models are available" (46:36). Fortunately, there is a consensus among researchers that these models can be grouped into four categories: 1) scoring models; 2) economic models; 3) constrained optimization models; and 4) decision theory models (4:41; 12:292; 21:21; 46:36).

This review will provide the reader with a concise description of each of the categories of models, including their uses, strengths, and weaknesses.

Scoring Models. Of the four categories listed above, scoring models are considered to be the least complex and easiest to use (12:292). Scoring models are used to obtain a relative ranking of competing research projects. Application of a scoring model begins with the development of standards against which each research project will be measured. Each project under consideration is then rated numerically as to how well it meets each of the standards. The individual scores are then summed, providing a relative ranking of the projects (21:22). Because scoring models can incorporate quantitative input data, they are often used to select

projects in the initial phases of research, when accurate cost and benefit data is difficult to generate (36:126).

Scoring models are often selected for their simplicity, ease of use, and flexibility. Measurement standards are easily developed, and do not have to conform to the strict input specifications that are typical of many other selection models (15:16).

In general, scoring models have two shortcomings. First, they provide only a relative ranking of competing projects. Scoring models are not designed to provide quantitative data, such as development costs or expected benefits. Second, scoring models are relatively informal, and lack the mathematical basis of many project selection techniques. Consequently, their results are often difficult to justify (15:18).

<u>Economic Models</u>. Economic models are used to rank projects based on their potential to provide financial benefits over time. A number of economic techniques such as "sales-to-benefit ratio, cash flow payback, net present value, benefit-to-cost ratio and internal rate of return" are used by these models (8:30). Because economic models rely heavily on cost and benefit data, they are most applicable during the later stages of a research effort, when the project has stabilized and accurate cost estimates can be made (21:21).

Economic models have two drawbacks. First, while projections of development costs and potential benefits are

very useful, accurate estimates are not easily obtained for projects in the earliest phases of research. Thus, economic models are not appropriate for project selection during this time. Second, economic models focus only on the financial benefits of a research project. Other possible selection factors, such as technical leadership and research prestige, are not considered (19:172).

Constrained Optimization Models. Constrained optimization models are used to select projects which are subject to resource constraints. Resource constraints typically involve funding or manpower limitations on the part of the laboratory. Constrained optimization models are based on mathematical optimization techniques such as linear, nonlinear, integer and dynamic programming (16:21). This category of models is most suited for large scale portfolio selection situations involving numerous interrelated projects (16:22; 46:38).

Although constrained optimization models are solidly grounded in MS/OR theory, the literature indicates that the use of these models is especially limited in R&D (12:295; 21:22; 46:39). According to Dr. William Souder and Tomislav Mandakovic,

> few real situations are linear, and forcing them into a linear programming model may result in a meaningless solution. To avoid such difficulties, a variety of integer and nonlinear programming models have been devised. However, the models are difficult to solve and the required input data is not easy to obtain with any degree of precision or confidence. (46:38)

Decision Theory Models. Decision theory models are used to predict the overall success of a sequence of interrelated projects over a period of time (16:19). This category is comprised of "decision tree, decision theory, utility theory, fault tree and relevance tree models" (46:-39).

The ability of decision theory models to consider a range of uncertainty is well documented as their major strength (1:152; 16:19; 17:29). In addition, decision theory models force a manager to consider the importance of each interrelated sub-project to the outcome of the overall project (16:20).

According to the literature, decision theory models have two major weaknesses. As with the constrained optimization models, the first drawback focuses on the amount and quality of input data required. These requirements include estimates of both the cost and benefit of each sub-project, as well as an estimate of the probability distribution for each project outcome (16:20). The second drawback concerns the complexity of the model itself. Farrell Jenson and John Lawson, authors of "Quantifying R&D Projects in the Face of Uncertainty" note that

> the major problem which will be faced in implementing this technique is building the confidence of management. Oftentimes, a good technique will not be implemented simply because it is not understood. (17:29)

Chapter Summary

This literature review began with an overview of the research devoted to the implementation of MS/OR techniques as a management tool. It examined the implementation gap - the gap between MS/OR theory and application - and investigated several variables which have been found to influence the implementation of MS/OR techniques in organizations. Three "generations" of implementation research were discussed. Those research efforts that are particularly applicable to this effort were discussed in detail.

The second section focused specifically on the implementation of R&D project selection techniques in organizations. First, the R&D environment was discussed. Next, some of the common barriers which have precluded the use of quantitative techniques were examined. Finally a comparison was made between the demands on the R&D manager in government and in private industry.

In the final section, four categories of quantitative project selection techniques were discussed, including their strengths and weaknesses. This literature review sets the stage for an examination of the R&D project selection process at the Air Force Wright Aeronautical Laboratories.

III. Methodology

Introduction

As noted in Chapter I, this research investigated three facets of the R&D project selection process at AFWAL. They consisted of 1) the methods used by managers to select R&D projects and allocate resources; 2) the attitudes and perceptions of managers toward the use of formal R&D project selection techniques; and 3) the factors affecting the adoption of these techniques by R&D managers.

To accomplish this task, surveys were administered to a non-random sample of 43 AFWAL managers. In addition, a subset of 12 managers were selected for follow-up interviews. The selection of respondents, survey instrument, statistical analyses, and interview process are described below.

Selection of Respondents

To adequately investigate the R&D project selection at AFWAL, it was necessary to seek out those managers who participated in the decision making process. The results of a 1985 AFIT thesis by Captain Jeremy Prince provided information leading to the identification of respondents. In his research, Prince found that "the final decisions on project selection are often reserved for the Branch Chief level or higher" (31:40). Consequently, a non-random sample of respondents occupying positions of Deputy Division Chief or higher was selected. Surveys were sent to all appro-

priate Division Chiefs, Chief Scientists, Deputy Directors and Directors. Surveys were not sent to Division Chiefs of staff organizations, however, the Director of Plans, the Director of Programs, and the Director of Management Information Systems were included.

Interviews were conducted with a subset of those who were surveyed. The interview candidates were chosen based on their response to survey question 17 (Appendix A). Only those who perceived that they had a strong influence on the project selection process were selected. In all, 12 interviews were conducted. To fully represent a cross-section of AFWAL managers, three interviews were conducted at each of the four laboratories.

Survey Instrument

In "Implementation and Organizational Validity: An Empirical Investigation," Schultz and Slevin note that

> one way to stimulate the orderly collection of data across a field of research as broad as implementation is to provide a meaningful and easily used instrument for data collection. (38:154)

The survey used this research was adapted from a Likert-based instrument provided by Dr. William Souder, a Professor at the University of Pittsburgh. An overview of Souder's research approach is included in Chapter II of this document. A more detailed account is contained in "Methodology for Increasing the Adoption of R&D Project Selection Models," and in "An Organizational Intervention Approach to

the Design and Implementation of R&D Project Selection Models" (44; 45).

The survey instrument used in this research is contained in Appendix A. Because the instrument was developed and used by an expert in the field of implementation research, its internal validity was not questioned (9:99).

Minor wording changes were made to Souder's instrument to make it directly applicable to AFWAL. In addition, the data from the Likert-based questions was analyzed at the interval level to take advantage of parametric statistical techniques. These modifications did not change the original intent of the survey instrument.

In his research, Souder utilized a longitudinal design to identify an originating set of variables that affect the adoption of R&D project selection techniques. The stability of the original set of variables was established by administering a second survey to the respondents following a training session in which formal R&D project selection techniques were discussed (45:74). Due to time limitations, this research focused on deriving only the initial set of adoption-affecting variables. Suggestions for a follow-on longitudinal effort are described in Chapter V.

The survey used in this research effort was divided into three parts. Each part is described below.

Part 1. The responses to survey questions 1 through 16 were used to investigate Research Question 1. These survey questions were designed to measure levels of familiarity and

usage of a variety of R&D project selection techniques, as well as to determine the extent to which R&D project selection techniques are used at AFWAL.

Questions 17 through 28 were designed to measure the respondent's attitudes and perceptions toward the use of formal project selection techniques. These questions provide the basis for the response to Research Question 2.

Part II. Part II of the survey was used to identify the factors affecting the adoption of R&D project selection techniques in response to Research Question 3. This portion of the survey was used to derive a set of adoption-affecting variables. The variables that were tested in this research were derived from the works of Dr. Souder, and are defined in Table 7 (44; 45).

Thirty survey questions were used to investigate the variables shown in Table 7. At least two questions were used to investigate each variable. The survey responses to questions designed around a particular variable were aggregated and averaged over the number of questions used. In some instances it was necessary to invert the Likert scale to be consistent with the remainder of the survey. This recoding process accounts for the all-positive correlation matrix shown in Chapter IV.

Part III. Part III was used to gather demographic data about the respondents. In addition to demographic data, Part III of the survey provides information such as the budgetary

Table 7.

Variable Definitions

1. Communicability. The ease with which the subject perceives that project selection techniques can be communicated to others.

2. Appropriateness of Outputs. The degree to which the subject perceives that a technique's output data is relevant.

3. Appropriateness of Mathematics. The degree to which the subject perceives that the mathematical basis for a technique is relevant.

4. Availability of Inputs. The perceived ease with which input data is obtained for a technique.

5. Upward Compatibility. The degree of perceived compatibility with superiors if project selection techniques are used in the decision process.

6. Downward Compatibility. The degree of perceived compatibility with subordinates if project selection techniques are used in the decision process.

7. Process Compatibility. The perceived compatibility of existing project selection processes and formal project selection techniques.

8. Uncertainty Absorption. The subject's perception of the ability of a project selection technique to reduce the amount of uncertainty in decisions.

9. Information Value. The subject's perception of the value of both the amount and type of information provided by the model.

10. Process Value. The perceived need for a formal structure in the subjects own decision-making

11. Willingness to Adopt. The subject's willingness to adopt a formal R&D project selection technique for routine and frequent use over a long period of time.

Adapted from (44; 45)

responsibilities of the respondents, and their willingness to attend a class or seminar on R&D project selection techniques.

Statistical Analyses

Several statistical techniques were used to analyze the survey data including: 1) analysis of variance; 2) reliability analysis; 3) correlation analysis; 4) factor analysis; and 5) descriptive statistics. The survey data was processed on AFIT's Academic Support Computer using the "Statistical Package for the Social Sciences - X" (SPSSx). The statistical analyses used in this research are described below. The results of this data analysis are presented in Chapter IV, and are discussed in Chapter V.

Analysis of Variance. A Kruskal-Wallis non-parametric analysis of variance was used to identify statistically significant differences between the responses of the managers at each of the four AFWAL laboratories. The Kruskal-Wallis test was selected for its robustness and conservatism (7:622).

The test was applied to survey questions 1 through 15 to identify statistically significant differences of the levels of familiarity and usage of R&D project selection techniques between the managers at each of the four AFWAL laboratories. The Kruskal-Wallis test was also used to identify differences in opinions among the managers in each lab (survey questions 17 through 27).

In each case, it was hypothesized that the responses from each laboratory would be identical. The Kruskal-Wallis tests were conducted a .05 level of significance.

Reliability, Correlation, and Factor Analysis. To identify factors affecting the adoption of R&D project selection techniques, a three-part approach was used. First, the internal reliability of the questions in Part II of the survey were checked using Cronbach's Alpha. In cases where Cronbach's Alpha could be increased by at least .1, the survey question was considered for elimination. With this criteria, survey question 29 was eliminated. Next, an 11 by 11 Pearson correlation matrix was derived by aggregating survey responses for each variable. All variables which were found to correlate with the variable "willingness to adopt" at a level of significance of .05 were considered to influence the adoption of R&D project selection techniques, and were included in the factor analysis.

In the final step, factor analysis was used to reduce the adoption-affecting variable set into factors.

> Factor analysis is a technique for removing redundancy from a set of correlated variables and representing the variables with a smaller set of derived variables, or factors. (18:378)

In the principal components extracts, all factors whose eigenvalue was greater than or equal to 1.0 were selected. According to Sam Kash Kachigan, "eigenvalues correspond to the equivalent number of variables which the factor represents" (18:387).

A varimax rotation was used to redistribute the explained variance among the extracted factors. This iterative technique is used to clarify the factor loadings, and aids in the assignment of variables to factors (18:389).

Variables were assigned to factors based on their loadings after the varimax rotation. Kachigan notes that "the analyst must use personal judgment as to what constitutes a meaningfully high loading" (18:393). Furthermore, he notes that "loadings of .3, .4, or .5 are most often used as lower bounds" (18:393). For conservatism, variables were assigned to a factor only if their factor loading was greater than .5.

The final step in the factor analysis process involved the naming of the factors. Again, Kachigan notes that this step involves personal judgment:

> Careless or casual naming of the factors might be completely misleading, jeopardizing the conclusions of the study. It is a fact that the identity of the contributing variables is often forsaken once a factor has been named, and the label is then communicated to those who would hope to apply the results of the research. It is wise, therefore, to always study the variables which define a factor. (18:394)

Because the stability of the adoption-affecting variables set derived from this research has not been confirmed by follow-on research, the advice offered by Kachigan must be considered.

When utilizing factor analysis techniques, it is necessary to consider the size of the survey sample in relation to the number of variables being tested. To measure

the adequacy of the sample, the Kaiser-Meyer-Olkin measure of sampling adequacy was used. This technique is described in Factor Analysis: Statistical Methods and Practical Issues (20:53). It should be noted that when investigating a small group, such as the R&D managers at AFWAL, sampling adequacy can be jeopardized if a larger group of adoption-affecting variables are tested. This must be considered in any follow-on efforts.

Descriptive Statistics. Frequency responses were used to summarize and present the data from Parts I and III of the survey. Inferences about management's use of and familiarity of R&D project selection techniques, as well as their perceptions of the utility of these techniques, were drawn from these frequency distributions, as well as from the data collected in the interviews.

Interview Process

As noted in Chapter II, intuition and expert judgment often play a significant role in R&D project selection (48:28). To fully investigate this, follow-on interviews were conducted to supplement the survey instrument. In Business Research Methods, C. William Emory notes that the interview process provides an excellent method for extracting detailed information. However, it is also noted that interviews are often costly to conduct because of travel costs to and from the interview location (9:161). Furthermore, busy executives

are often hesitant to grant long interviews due to constraints on their time.

Nonetheless, because of the proximity of AFIT to the laboratories, a series of semi-structured interviews were conducted, both in person and via telephone. Appendix C contains a list of the interview questions. Candidates were initially contacted and interviewed by telephone. After receiving their consent, an interview was conducted by telephone, unless a personal interview was requested. Three of the 12 interviews were conducted in person. The interview questions contained in Appendix C were used only as a guide. The respondents were encouraged to discuss any thoughts they had concerning the R&D project selection process.

Chapter Summary

This chapter provided an overview of the methodology used in this research effort. First, the basis for selecting the non-random sample of AFWAL managers was presented. Next, the survey instrument and the statistical techniques used to process the survey data were discussed. Finally, the personal and telephone interview process was discussed.

In the following chapter, the results of the survey data are presented. These results are discussed in detail in Chapter V.

IV. Results

Overview

This chapter provides a summary presentation of the responses to the survey instrument. These responses are discussed and analyzed in detail in Chapter V.

Of the 43 surveys administered, 32 were completed and returned (74.4 percent). Tabular frequency distributions are presented for both the demographic data and attitudinal measures. In some instances, column percentages do not sum to 100 percent due to computer rounding or missing values.

A Kruskal-Wallis analysis of variance was used to test for statistically significant differences between the four AFWAL laboratories in familiarity with, use of, and opinions about R&D project selection techniques. The identification of adoption-affecting variables and their associated factors was accomplished using a three-step approach. First, the internal reliability of the survey questions in Part II was assessed using Cronbach's Alpha. Next, a correlation matrix was developed to identify associations between the ten test variables and the variable "willingness to adopt." Finally, factor analysis was performed, utilizing a varimax rotation, to reduce the initial adoption-affecting variables set into factors.

Demographic Data

Demographic data was collected on all respondents. The demographic data includes the age, rank, sex, education

(highest degree obtained, course-work in MS/OR and laboratory management, and the respondent's willingness to attend a course in R&D project selection techniques), and organizational affiliation of each respondent. All respondents were male. Tables 8 through 12 provide a summary of the demographic data.

Table 8.

Distribution of Respondents by Age

Age (years)		Frequency	Percent
20-25		0	0.0
26-30		0	0.0
31-35		0	0.0
36-40		1	3.1
41-45		4	12.5
46-50		10	31.3
51-55		9	28.1
56 +		8	25.0
		-------	-------
	Total	32	100.0

Table 9.

Distribution of Respondents by Organization

Organization		Frequency	Percent
Aero Propulsion Lab		5	15.6
Avionics Lab		8	25.0
Flight Dynamics Lab		9	28.1
Materials Lab		8	25.0
AFWAL Staff Organizations		2	6.3
		-------	-------
	Total	32	100.0

Table 10.

Distribution of Respondents by Highest Educational Degree

Degree	Frequency	Percent
High School	0	0.0
Associate's	0	0.0
Bachelor's	8	25.0
Master's	16	50.0
Ph.D.	8	25.0
	-------	-------
Total	32	100.0

Table 11.

Distribution of Respondents by Applicable Course-work

Have attended Course in:	Response			
	Yes		No	
	Freq.	Percent	Freq.	Percent
MS/OR	26	81.3	6	18.8
Lab Management	27	84.4	5	15.5

Table 12.

Respondent's Willingness to Attend a Course
In R&D Project Selection Techniques

Response			
Yes		No	
Frequency	Percent	Frequency	Percent
26	80	6	20

Usage, Familiarity, and Attitudinal Data

The information contained in Table 13 summarizes the results of survey questions 1 through 15. These questions measure the respondent's familiarity with and use of several of the most popular R&D project selection techniques.

Survey questions 17 through 27 were analyzed together to measure the respondent's attitudes and perceptions toward the utility of R&D project selection techniques.

Survey question 17 examined the respondent's perceived influence on his organization's project selection process. These responses were used to assess the adequacy of the non-random sample. Table 14 provides a summary of the data.

The respondent's perceptions concerning the adequacy of his organization's project selection process was investigated in survey question 18. The results are summarized in Table 15.

Survey questions 19 and 20 were designed to measure the respondent's attitudes concerning the potential worth of R&D project selection techniques, both as a personal management tool, and as a tool for use by his subordinates. These responses are contained in Tables 16 and 17.

A series of four questions were used to assess the respondent's overall confidence in the capabilities of R&D project selection techniques. Question 21 sought to determine how important an organizational decision to use R&D project selection techniques on all R&D project evaluations would be to the respondent. Question 22 asked the

Table 13.

Familiarity with and Use of R&D Project Selection Techniques

Technique	Not Familiar (Percent)	Familiar (Percent)	Use Regularly (Percent)
Q-Sort	96.9	3.1	0.0
Checklists	53.1	31.3	15.6
Scoring Models	62.5	34.4	3.1
Delphi	18.8	65.6	15.6
Cost/Benefit Ratios	25.0	65.6	9.4
Payback Period	46.9	46.9	6.3
Net Present Value/Internal Rate of Return	81.3	15.6	3.1
Portfolio Models	90.6	9.4	0.0
Risk Analysis/ Monte Carlo	43.8	56.3	0.0
Decision Trees/ Decision Analysis	25.0	71.9	3.1
Linear Programming	62.5	37.5	0.0
Integer Programming	90.6	9.4	0.0
Nonlinear Programming	84.4	15.6	0.0
Dynamic Programming	81.3	18.8	0.0
Goal Programming	87.5	9.4	3.1

Table 14.

Perceived Influence on the Project Selection Process

Response	Likert Scale	Frequency	Percent
Very Strong Influence	1	6	18.8
	2	10	31.3
	3	5	15.6
Some Influence	4	5	15.6
	5	3	9.4
	6	1	3.1
No Influence	7	2	6.3
		-------	-------
	Total	32	100.0

Table 15.

Evaluation of the Current Project Selection Process

Response	Likert Scale	Frequency	Percent
Needs Great Improvement	1	4	12.5
	2	2	6.3
	3	16	50.0
Uncertain	4	0	0.0
	5	4	12.5
	6	5	15.6
Needs No Improvement	7	1	3.1
		-------	-------
	Total	32	100.0

respondent to indicate his preference if such a decision were made. Survey questions 23 and 24 were similar to questions 21 and 22, however, in questions 23 and 24, the organizational decision concerned the use of R&D project selection techniques on half of their project selection decisions.

Table 16.

Evaluation of R&D Project Selection Techniques as a Personal Management Tool

Response	Likert Scale	Frequency	Percent
Extremely Beneficial	1	1	3.1
	2	8	25.0
	3	13	40.6
No Benefit/Uncertain	4	7	21.9
	5	1	3.1
	6	1	3.1
Extremely Detrimental	7	1	3.1
	Total	32	100.0

Table 17.

Evaluation of R&D Project Selection Techniques as a Management Tool for Subordinates

Response	Likert Scale	Frequency	Percent
Extremely Beneficial	1	3	9.4
	2	8	25.0
	3	11	34.4
No Benefit/Uncertain	4	7	21.9
	5	2	6.3
	6	1	3.1
Extremely Detrimental	7	0	0.0
	Total	32	100.0

Together, these four questions examined the levels of conviction and confidence that managers have in these techniques. The responses are summarized in Tables 18 through 21.

Table 18.

Perceived Importance of a Decision to Use R&D Project Selection Techniques on All Projects

Response	Likert Scale	Frequency	Percent
Very Important	1	4	12.5
	2	5	15.6
	3	6	18.8
Uncertain	4	6	18.8
	5	2	6.3
	6	3	9.4
Very Unimportant	7	6	18.8
		-------	-------
	Total	32	100.0

Table 19.

Recommendation Concerning the Use of R&D Project Selection Techniques on All Projects

Response	Likert Scale	Frequency	Percent
Definitely Use	1	2	6.3
	2	3	9.4
	3	7	21.9
Uncertain	4	8	25.0
	5	2	6.3
	6	4	12.5
Definitely Do Not Use	7	6	18.8
		-------	-------
	Total	32	100.0

Survey question 25 was used to measure the respondent's opinions about the likelihood of developing a R&D project selection technique that would be beneficial to the organization. The results are summarized in Table 22.

Table 20.

Perceived Importance of a Decision to Use R&D Project Selection Techniques on Fifty Percent or More of Projects

Response	Likert Scale	Frequency	Percent
Very Important	1	6	18.8
	2	2	6.3
	3	7	21.9
Uncertain	4	6	18.8
	5	3	9.4
	6	1	3.1
Very Unimportant	7	7	21.9
		-------	-------
	Total	32	100.0

Table 21.

Recommendation Concerning the Use of R&D Project Selection Techniques on Fifty Percent or More of Projects

Response	Likert Scale	Frequency	Percent
Definitely Use	1	3	9.4
	2	4	12.5
	3	7	21.9
Uncertain	4	8	25.0
	5	1	3.1
	6	5	15.6
Definitely Do Not Use	7	3	9.4
		-------	-------
	Total	31*	96.9 *

* 1 Missing Value

Finally, survey questions 26 and 27 measured the extent to which the respondent felt pressure to quantitatively justify R&D resource allocations. Table 23 summarizes the respondents' perceptions concerning the amount of pressure

Table 22.

Perceived Likelihood of a Beneficial
R&D Project Selection Technique Being Developed

Response	Likert Scale	Frequency	Percent
Very Likely	1	3	9.4
	2	4	12.5
	3	4	12.5
Uncertain	4	5	15.6
	5	4	12.5
	6	4	21.9
Very Unlikely	7	7	3.1
		-------	-------
	Total	31*	96.9 *
* 1 Missing Value			

Table 23.

Perceived Pressure Exerted from Within AFWAL
to Quantitatively Justify R&D Expenditures

Response	Likert Scale	Frequency	Percent
Extreme Pressure	1	1	3.1
	2	3	9.4
	3	6	18.8
Some Pressure	4	9	28.1
	5	6	18.8
	6	6	18.8
No Pressure	7	1	3.1
		-------	-------
	Total	32	100.0

generated from within AFWAL. Table 24 summarizes the respondents' perceptions concerning the amount of pressure being exerted from outside sources (e.g. the Air Force

Table 24.

Perceived Pressure Exerted from Outside AFWAL to Quantitatively Justify R&D Expenditures

Response	Likert Scale	Frequency	Percent
Extreme Pressure	1	4	12.5
	2	5	15.6
	3	9	28.1
Some Pressure	4	6	18.8
	5	2	6.3
	6	2	6.3
No Pressure	7	4	12.5
	Total	32	100.0

Office of Scientific Research, Air Force Systems Command, etc.).

In survey question 28, the respondent was asked to describe any positive or negative experiences he has had while using, or attempting to use a formal project selection technique. Responses to this question are presented in Appendix C. Numbers were assigned to each narrative only to provide a method for referencing these statements in the following chapter. The identities of the respondents are confidential.

The Kruskal-Wallis analysis of variance tests showed no significant differences in familiarity with, use of, or attitudes toward project selection techniques between the four AFWAL laboratories at a .05 level of significance.

Adoption-Affecting Variables and Factors

As noted in Chapter III, a three-step process was used to identify a set of adoption-affecting variables and group them into factors. The results of this process are presented here.

Cronbach's Alpha. A reliability analysis was performed to assess the internal reliability of the 30 questions in Part II of the survey instrument. As noted in Chapter III, the survey responses designed around a particular variable were aggregated to form a single measure of that variable. The variables, the survey questions from which they were derived, and the resulting values of Cronbach's Alpha are summarized in Table 25. Based on the results of this analysis, survey question 29 was eliminated.

Pearson Correlation Coefficients. The next step in the process was to identify a statistically significant set of adoption-affecting variables. A correlation matrix was generated for all eleven variables (see Table 7). Each variable was examined for its degree of correlation with the variable "willingness to adopt." Of the ten variables tested, nine were found to correlate with "willingness to adopt" at a level of significance of .05. The variable "communicability" did not correlate significantly. The nine remaining variables were used as the input for the factor analysis. It should be noted that several variables also exhibited significant interrelationships (.05 level of

Table 25.

Reliability Analysis

Variable Name	Survey Questions	Cronbach's Alpha
Communicability	38, 39, 52	.7641
Appropriateness of Outputs	46, 54, 55	.6893
Appropriateness of Mathematics	47, 56	.4181
Availability of Inputs	48, 57	.8538
Upward Compatibility	32, 41	.7033
Downward Compatibility	33, 42	.8078
Process Compatibility	30, 37	.5543
Uncertainty Absorption	34, 44	.8872
Information Value	31, 35, 36, 43	.7649
Process Value	40, 53, 58	.7204
Willingness to Adopt	45, 49, 50, 51 (29 eliminated)	.8702

significance) with the other adoption-affecting variables. Table 26 shows the Pearson correlations between the variables. The aggregation and recoding procedures described in Chapter III account for the positive nature of the correlation matrix.

Factor Analysis. Factor analysis was used to reduce the adoption-affecting variables set into factors. Due to

Table 26

Correlation Matrix

Variables	1	2	3	4	5	6	7	8	9	10	11
1. Communicability	1.0000										
2. Approp. of Outputs	.5572**	1.0000									
3. Approp. of Math	.3777*	.2439	1.0000								
4. Avail. of Inputs	.5672**	.5274**	.2649	1.0000							
5. Upward Compat.	.3019*	.3647*	.0913	.1158	1.000						
6. Downward Compat:	.2179	.5335**	.2347	.3452*	.4697**	1.0000					
7. Process Compat.	.4907**	.5385**	.4457**	.5372	.4897**	.6802**	1.0000				
8. Uncert. Absorb.	.2650	.6335**	.1880	.1644	.5841**	.7668**	.5712**	1.0000			
9. Info. Value	.1014	.4622**	.2939	.1440	.4712**	.6749**	.4741**	.8460**	1.0000		
10. Process Value	.1952	.4648**	.3591*	.5283**	.3077*	.7069**	.6967**	.5947**	.5893**	1.0000	
11. Willing to Adopt	.1140	.6216**	.3857*	.4038*	.5083**	.7634**	.6600**	.7315**	.7263**	.7663**	1.0000

* .05 Level of Significance
** .01 Level of Significance

the relatively large number of variables, there was concern about the adequacy of the sample size. A Kaiser-Meyer-Olkin measure of sampling adequacy was calculated and found to be .8054. This value, according to Jae-on Kim and Charles Mueller, can be considered "meritorious." (20:54).

Two factors were extracted, and account for 66.7 percent of the variance of the data. A varimax rotation was used to redistribute the explained variance among the two factors. The factor loadings resulting from the varimax rotation are shown in Table 27.

Chapter Summary

This chapter provided a summary presentation of the results of this research effort. The results, along with the interview data, form the basis for the responses to the three research questions posed in Chapter I. In the following chapter, each research question is restated and answered.

Table 27.

Factor Loadings

Variable Name	Factor 1	Factor 2
Communicability	(Did not correlate significantly with "Willingness to Adopt")	
Appropriateness of Outputs	.4525	.5526
Appropriateness of Mathematics	.0688	.6191
Availability of Inputs	-.0025	.8609
Upward Compatibility	.7393	.0253
Downward Compatibility	.7688	.4034
Process Compatibility	.5192	.6640
Uncertainty Absorption	.9264	.1860
Information Value	.8487	.1769
Process Value	.5300	.6532

V. Analysis and Discussion

Overview

This chapter provides an analysis and discussion of the results presented in Chapter IV. Both the survey data and the information gathered in interviews was used to develop these results. In this chapter, each research question is listed, followed by a detailed response. The research findings presented in this chapter are applicable to all four AFWAL laboratories since the Kruskal-Wallis analysis of variance indicated that there were no statistically significant differences between the responses between the four laboratories.

Research Question 1

> What methods do managers use to select R&D projects and allocate laboratory resources at the Air Force Wright Aeronautical Laboratories?

Use of R&D Project Selection Techniques. Formal project selection techniques play a minor role in the project selection process at AFWAL. Furthermore, the respondents, in general, are not familiar with most R&D project selection techniques. Over half of the respondents indicated that they were not familiar with 10 out of the 15 techniques listed in the survey. The techniques which were recognized by at least half of the respondents are listed in Table 28.

Table 28.

Ranking of R&D Project Selection Techniques By Familiarity *

Technique	Familiar With and/or Use	
	Frequency	Percent
Delphi	26	81.2
Cost/Benefit Ratios	24	75.0
Decision Analysis	24	75.0
Risk Analysis/Monte Carlo Simulation	18	56.3
Payback Period	17	53.2

* Includes only those techniques which were recognized by 50 percent or more of the respondents

As expected, the use of R&D project selection techniques was also limited. Only 25% of the respondents indicated that they used a formal R&D project selection technique.

Furthermore, only seven of the techniques listed in the survey were used by any of the respondents. The seven techniques are shown in Table 29. They are rank-ordered based on their rate of use.

Because the education level of the respondents was high, the low level of familiarity with these techniques was surprising. Table 10 showed that 75 percent of the respondents had obtained at least a Master's Degree, and a very large percentage of respondents had completed course-work in related topics such as MS/OR (81.3 percent) and Laboratory

Table 29.

Ranking of R&D Project Selection Techniques By Use

Technique	Used Regularly	
	Frequency	Percent
Checklists	5	15.6
Delphi	5	15.6
Cost/Benefit Ratios	3	9.4
Payback Period	2	6.3
Net Present Value/ Internal Rate of Return	1	3.1
Goal Programming	1	3.1
Decision Analysis	1	3.1

Management (84.4 percent). Although the familiarity and usage were low, the respondents did indicate a desire to learn more about these techniques. Over 80 percent of the respondents indicated that they would be willing to attend a course or seminar on the topic of R&D project selection techniques.

It should also be noted that during the interview process there were several indications that managers utilized processes which were very similar to some formal project selection techniques. However, most managers did not indicate knowledge of the names of the formal techniques. This was especially true of those techniques which utilize

qualitative selection criteria, such as checklists, scoring models, and Delphi techniques.

Pressure to Quantify R&D Expenditures. Table 24 indicated that AFWAL managers experienced moderate amounts of pressure from outside sources (e.g. Systems Command, Air Force Office of Scientific Research) to quantify their R&D expenditures. On a seven-point Likert scale, over half of the respondents marked either 1, 2, or 3, with the value 1 corresponding to "Extreme Pressure," and the value 7 to "No Pressure." Furthermore, only 25.1 percent of the respondents marked 5, 6, or 7 (28.1 percent marked the middle value "Some Pressure").

On the other hand, the amount of pressure being exerted from within AFWAL to quantify R&D expenditures was somewhat less, as shown by Table 23. In this case, only 31.3 percent of the respondents marked either 1, 2, or 3, while 40.7 percent marked 5, 6, or 7 (28.1 percent marked the middle value "Some Pressure").

Therefore, while it is clear that managers are faced with moderate amounts of pressure to quantify their R&D expenditures, especially from sources outside AFWAL, they do not choose to utilize formal R&D project selection techniques to respond to this pressure. This finding prompts two questions. First, how are R&D projects evaluated if formal techniques are not used? Second, why would a manager decide against using these techniques? The first question is

addressed below. The second question will be addressed in the response to Research Question 3.

The R&D Project Selection Process. Although formal project selection techniques are not widely used at AFWAL, R&D managers in all four laboratories indicated that they do rely on a systematic process to evaluate project proposals and allocate laboratory resources. This section provides a description of the R&D project selection process at AFWAL. It is followed by a discussion of several specific characteristics of the process. Because intuition and expert judgment often play a significant role in the R&D project selection process, the interviews conducted in support of this research were especially helpful in obtaining a complete description of the process (48:28).

Prior to this discussion, background information will be presented concerning the categories of R&D conducted at AFWAL, and the organizational structure of a typical laboratory.

There are four major categories of research conducted at AFWAL: basic research; exploratory development; advanced development; and production base support (32:2). These categories of research are commonly referred to by the program element number under which they are funded. Overall, the primary emphasis is on exploratory and advanced development work. However, the Materials Laboratory performs a significant amount of research in the area of manufacturing technology to support the production base.

Table 30 shows the funding appropriations for each major program element as a percentage of each laboratory's total expenditures. The data in Table 30 includes direct laboratory funds, as well as funds provided by the Air Force Office of Scientific Research (AFOSR) for basic research. Research funded by other external organizations (including other Air Force and non-Air Force organizations) is not included. The engineering development (6.4) work conducted by the Avionics and Flight Dynamics Laboratories is in support of research efforts which are in transition from the

Table 30.

Proportionate Laboratory Funding by Program Element

	AFWAL Laboratory (Percent of Total Funds)			
Program Element	Avionics	Flight Dynamics	Materials	Aero-Prop.
Basic Research (6.1)	2.7	4.4	3.9	4.6
Exploratory Development (6.2)	25.4	43.8	31.7	42.4
Advanced Development (6.3)	50.6	43.3	10.8	50.4
Engineering Development (6.4)	17.8	5.2	0.0	0.0
Production Base Support (7.8)	0.0	0.0	48.9	0.0
Other (6.5, 7.1)	3.5	3.3	4.7	2.6
Total	100.0	100.0	100.0	100.0

Source (11)

laboratory to a program office. Miscellaneous expenditures include such items as small business innovative research efforts, and the acquisition and maintenance of embedded computer resources. Beginning with basic research, each category of R&D becomes progressively more application-oriented. The purpose of this data is to demonstrate the emphasis placed on each category of research within the laboratories. With its heavy emphasis on exploratory development, advanced development, and production base support, it is clear that the R&D conducted at AFWAL is very "mission oriented." As noted in Chapter II, the mission-oriented nature of public sector R&D organizations has had an effect on the implementation of R&D project selection techniques. This point will be discussed in more detail later in this chapter.

The organizational structure of a typical AFWAL laboratory is depicted in Figure 2. The four laboratories range in size from 350 employees to over 700. This background on the funding appropriations and organizational structure of AFWAL will help to clarify the following discussion of the R&D project selection process.

The project selection process at each laboratory is very similar, and generally occurs annually. The process is timed to support the submission of the Program Objective Memorandum.

Technical teams consisting of engineers and scientists

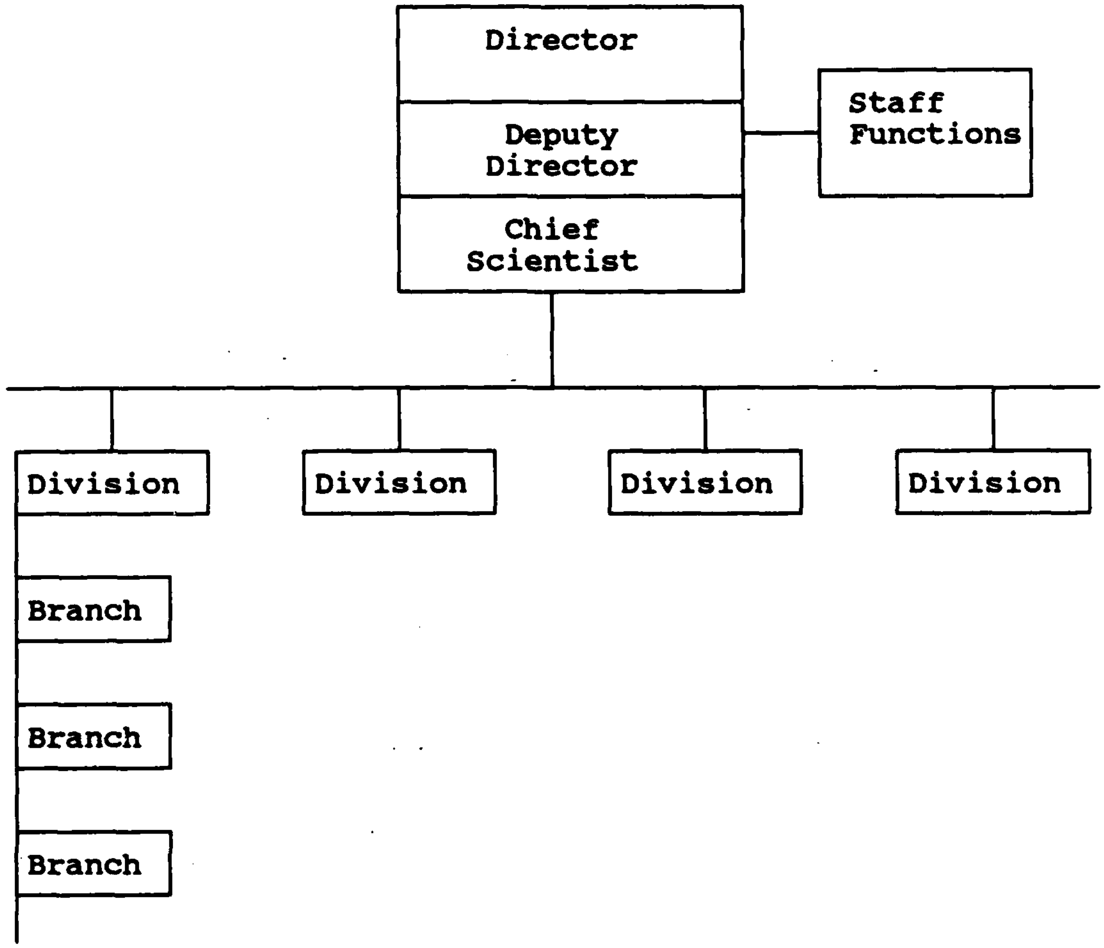

Figure 2. Organizational Structure of a Typical AFWAL Laboratory (Adapted from 27)

are formed to provide progress reports and proposals for new projects to upper management. The teams are formed around a specific technological area. The members of the technical teams mayor may not be from the same branch, depending on the amount of technical integration required. The technical area teams are responsible for all categories of R&D within their discipline (i.e. basic research, exploratory development, advanced development, and production base support, if

applicable). The information developed by the technical teams is provided, in briefing form, to the "corporate board."

The corporate board is a high-level management group typically comprised of the Director, Deputy Director, Chief Scientist, Director of Planning, and Division Chiefs within the laboratory. After reviewing briefings from each of the technical teams, the corporate board then makes project selection decisions for the laboratory.

Although the project selection process was found to be similar for each laboratory, the process used by the Materials Laboratory was found to be somewhat more structured. In the Materials Laboratory process, the corporate board provides each technical team with feedback in the form of written questions following their presentation. The technical teams are then required to respond to these questions in a follow-up briefing before final decisions are made.

Despite minor differences between the project selection process in each laboratory, the corporate board by and large relies on intuition and expert judgment as the primary means of making project selection decisions.

The preceding discussion provided a brief overview of the project selection process. In the following sections, several of the more pertinent aspects of the project selection process will be discussed in detail.

Use of Off-sites. Several respondents indicated that the corporate board often held project selection meetings in "off-site" locations. These "off-sites" are typically held at local convention centers, and are designed to promote frank and honest discussion during the project selection process.

Technology Push and Requirements Pull. From interviews with R&D managers, it was readily apparent that research at AFWAL is heavily influenced by "requirements pull" as opposed to "technology push." Thus, it is important for scientists and engineers to link their R&D projects to existing or planned Air Force programs to increase the chances that their projects will be continued or initiated by the corporate board.

As shown in Table 30, it was found that the majority of funding is concentrated in exploratory and advanced development, and production base support, rather than basic research. In fact, most managers indicated that demonstrating that a R&D project benefits a specific Air Force program is a primary selection criterion. As such, it is probably not coincidental that three of the seven most frequently used project selection techniques are designed to evaluate projects in terms of economic benefits (see Table 29).

Impact of Budget Constraints. There was nearly unanimous agreement among those interviewed that budget constraints have a significant impact on the project selection process. For the most part, respondents indicated

that budget constraints force managers to select those R&D projects which are less risky, and provide more immediate short-term benefits. Because of this, some managers felt that budget constraints make the job of project selection easier. However, most managers felt that budget constraints challenge them to achieve a balanced portfolio of R&D projects, which included both long-term, high-risk projects, as well as more immediate, high-payoff projects.

In summary, it was found that formal project selection techniques are not widely used by AFWAL managers, despite some pressure to quantitatively justify R&D expenditures. It was also found that, although R&D project selection techniques are not widely used, all four laboratories employed a systematic project selection process. Furthermore, it was shown that expert judgment plays a primary role in the selection process, and that managers often utilize "off-site" meetings to encourage candid discussion. Finally, it was shown that both "requirements pull" and budget constraints have a significant influence on the project selection process.

Research Question 2

> What are the attitudes and perceptions of AFWAL R&D managers toward the use of formal R&D project selection techniques?

The reply to this research question is derived from the responses to survey questions 17 through 25, as well as from the interviews. Survey questions 17 through 25 measured the

attitudes and perceptions of the respondents concerning their project selection processes and the potential benefit of formal R&D project selection techniques. The interviews were especially helpful in determining why managers are reluctant to utilize these techniques. The results are discussed below.

Adequacy of Existing System. A majority of respondents (62.5 percent) indicated that they were generally satisfied with the current project selection process in their laboratory (survey question 29). However, approximately two-thirds of the respondents felt that the process needs at least some improvement (Table 16). From this, it can be inferred that AFWAL managers are somewhat motivated to investigate the capabilities of R&D project selection techniques.

Utility of R&D Project Selection Techniques. Tables 16 and 17 showed that a majority of managers felt that a project selection technique would be beneficial to them (68.8 percent); 68.8 percent also felt that such a technique would be beneficial to their subordinates. However, an actual decision to utilize such techniques brought mixed responses. The data in Table 19 showed that managers felt somewhat strongly about an organizational decision to implement R&D project selection techniques for all project selections - 46.9 percent of the respondents felt that such a decision was relatively important, while 34.5 perceived it to be relatively unimportant (18.8 percent were uncertain). The

respondent's personal recommendations on such a decision were equally divided, with 37.6 percent for, 37.6 percent against, and the remainder undecided.

The response to the question concerning the use of project selection techniques on half of the respondent's project selections showed similar results. Table 21 shows that 47 percent of the respondents felt that an organizational decision to implement these techniques was important, while 34.4 percent thought it to be relatively unimportant (18.8 percent undecided). Furthermore, 43.8 percent of the respondents were generally in favor of using formal techniques on half of their projects, while 28.1 percent were not (25 percent undecided).

In addition, respondents were skeptical about the probability of developing a project selection technique that would greatly enhance the effectiveness of their project selection decisions (35.5 percent found it likely; 46.9 percent found it unlikely; 16.1 percent were uncertain).

In summary, respondents were generally satisfied with their current project selection process; however, many felt it needed some improvement. Furthermore, although a majority of the respondents indicated that a formal project selection technique would be beneficial, most felt that it is unlikely that such a technique could be developed that would adequately consider the wide range of pertinent selection criteria. Finally, it can be inferred that managers are, for

the most part, skeptical about the promise of formal project selection techniques.

The final research question sought to identify the specific variables and factors that affect the adoption of R&D project selection techniques by AFWAL managers.

Research Question 3

> What factors affect management's willingness to adopt formal R&D project selection techniques?

Of the ten variables tested, nine were found to correlate with "willingness to adopt" at a .05 level of significance (see Table 26). The variables used in this research were previously defined in Table 7. The variable "communicability" did not correlate significantly with "willingness to adopt."

Two factors were extracted based on their eigenvalues (greater than or equal to 1.0) in the initial principal components extraction. These two factors account for 66.7 percent of the total variance of the data. A varimax rotation was used to distribute the variance among the two factors. It was determined apriori that variables which had a factor loading of .5 or greater would be included in that factor. The nine variables loaded as shown in Table 31. In keeping with the decision rule for assigning variables to factors, the variables "process value" and "process compatibility" were included in both factors.

As noted by Kachigan, factor names should "represent a common element or abstraction of the individual variables

which loaded highly on the factor" (18:393). After analyzing each factor, names were selected as shown in Table 31.

The variables which comprise the first factor are related to the process of organizational decision making.

Table 31.

Factor Names and Variable Loadings

Factors and Variables	Factor Loadings
Factor 1: Organizational Decision Making	
Uncertainty Absorption	.9296
Information Value	.8487
Downward Compatibility	.7688
Upward Compatibility	.7393
Process Value *	.5300
Process Compatibility *	.5192
Factor 2: R&D Project Selection Techniques	
Availability of Inputs	.8609
Process Compatibility *	.6640
Process Value *	.6534
Appropriateness of Mathematics	.6191
Appropriateness of Outputs	.5526

* Variable loaded on both factors

This first factor shows that, as a group, the respondents do not feel that formal project selection techniques will reduce uncertainty about decisions provide additional information or greatly facilitate communication within the organization. Furthermore, this factor shows that the respondents do not feel that a formal project selection technique is necessary, nor would it be compatible with the existing process.

The variables which comprise the second factor are primarily related to the R&D project selection techniques themselves. This factor shows that the respondents feel that 1) the input data required by formal techniques would be difficult to develop; 2) that the mathematics involved with the quantification of project selection decisions is more complex than necessary; and 3) that the outputs from these techniques would not yield information which is relevant to the project selection process.

Although these results show that the respondents generally have negative attitudes toward capabilities of R&D project selection techniques, it must be noted that these results represent an initial set of variables which are based only on the respondents' perceptions. Research conducted by Souder showed that a "negative-to-positive shift in adoption attitudes" occurred when respondents were provided with education and training in the use of these techniques (45:75). Thus, until this has been accomplished, the stability of the adoption-affecting variables can not be

verified. Nonetheless, these results serve as a basis for further analysis by providing a characterization of the existing project selection process and establishing an initial set of adoption-affecting variables.

Chapter Summary

This chapter provided an analysis and discussion of the findings of the research effort. Using the results of the survey data presented in Chapter IV, as well as the data collected in the interviews, each of the three research questions was addressed in detail.

The following chapter provides a summary of the conclusions that can be drawn from this research, as well as suggested recommendations for future research.

VI. Conclusions and Recommendations

This chapter provides a summary of the key findings of this research effort. Recommendations pertaining to both the R&D project selection process at AFWAL and this research effort are also suggested.

Conclusions

1. From the survey data, it can be concluded that formal R&D project selection techniques play a minor role in the project selection process at AFWAL. Only 25 percent of the respondents indicated that they used a formal technique as part of their project selection process. Furthermore, as a group, managers at AFWAL are not familiar with many of the most popular techniques. Of the 15 techniques listed in the survey, only five were recognized by more than half of the respondents. The levels of familiarity with, and usage of R&D project selection techniques did not differ significantly between the four laboratories.

2. Although AFWAL managers do not rely heavily on formal project selection techniques, they do utilize systematic methods for reviewing technical progress, selecting R&D projects, and allocating laboratory resources.

The project selection processes utilized by the laboratories were found to be similar. At the laboratory level, technical progress and proposals for new R&D projects are formally reviewed on an annual basis. Technical teams, comprised of laboratory scientists and engineers, are

responsible for developing this information, and providing it, in briefing format, to a "corporate board." The corporate board typically consists of the Director, Deputy Director, Chief Scientist, and Division Chiefs of each laboratory. The corporate board generally relies on expert judgment to reach a consensus on project selection decisions. Several managers noted that "off-site" meetings were used to facilitate strategic planning.

3. Managers felt that there was a moderate amount of pressure being exerted from outside sources (e.g., Air Force Office of Scientific Research, Air Force Systems Command) to quantitatively justify their R&D expenditures. The amount of pressure being generated from within AFWAL was perceived to be somewhat less.

4. The R&D project selection process at AFWAL is heavily influenced by "requirements pull," i.e., the mission requirements of the Air Force drive the project selection process. For advanced development (6.3) work in particular, the objective of management becomes one of evaluating the effectiveness of R&D projects undertaken in response to a specific Air Force need, as opposed to selecting R&D projects for their potential to advance scientific knowledge.

This emphasis on exploratory and advanced development, and production base support (the percentage of laboratory expenditures devoted to these areas is shown in Table 30), indicates that AFWAL R&D is driven primarily by "requirements pull" as opposed to "technology push." As noted in Chapter

II, the mission-oriented nature of public sector R&D often places unique constraints on the R&D manager, especially in terms of quantifying research benefits. This fact may place constraints on the applicability of many R&D project selection techniques. Thus, due to the nature of the military R&D environment, R&D expenditures are often justified by the establishment of formal links to the "user" such as memorandums of agreement.

5. Budget constraints have a significant impact on the project selection process at AFWAL. In general, managers felt that budget constraints force them to focus on short-term, high-payoff projects which exhibit low technical risk. When faced with budget constraints, managers noted that the challenge is to maintain a balanced research portfolio, consisting of both long- and short-term research efforts, to ensure that the laboratory maintains an innovative edge, and does not become myopic.

6. Respondents indicated that they were, in general, satisfied with the current R&D project selection process in their laboratories. Although many felt that a technique designed to help them evaluate and select R&D projects would be very beneficial, a majority felt that the likelihood of developing such a technique was low. Even if such techniques were developed, respondents were divided as to whether they would implement them in their project selection process. The attitudes and perceptions of the respondents did not differ significantly between the four laboratories.

7. Nine variables were found to be associated with management's willingness to adopt formal R&D project selection techniques at a .05 level of significance.

The variables are 1) the appropriateness of the outputs provided by project selection techniques; 2) the appropriateness of the mathematics used to derive the outputs; 3) the availability of input data; 4) the ability of project selection techniques to facilitate upward communication; 5) the ability of project selection techniques to facilitate downward communication; 6) the compatibility of formal techniques with the existing project selection process; 7) the informational value of project selection techniques; 8) the ability of project selection techniques to remove uncertainty in the decision-making process; and 9) the respondents' need for structure in their own decision process.

These nine variables constitute an initial set of adoption-affecting variables, based on the respondents perceptions about formal R&D project selection techniques. They were factored into two groups, which accounted for 66.7 percent of the variation of the data. The results showed that the factors that affect management's willingness to adopt formal project selection techniques are related to: 1) the effect of formal project selection techniques on the organizational decision-making process; and 2) the characteristics of the R&D project selection techniques themselves.

The results also indicate that the respondents, based on their initial perceptions and current level of knowledge, generally feel that formal R&D project selection techniques have limited utility as a management tool.

At this point, it is important to reiterate the results of research conducted by Dr. William Souder on this subject. Dr. Souder found that negative-to-positive attitude shifts occurred after respondents attended training sessions on the theory and application of formal project selection techniques (45:75). A recommendation concerning training is discussed in the next section.

This investigation of the R&D project selection process at AFWAL provides 1) a characterization of the project selection process; 2) a characterization of the attitudes and perceptions of AFWAL managers toward the utility of R&D project selection techniques; and 3) the identification of an initial set of variables which affect management's willingness to adopt R&D project selection techniques. Together, this information serves as a basis for follow-on research. When the stability of the adoption-affecting variables set is established, the resulting data will provide the information necessary to evaluate and/or develop R&D project selection techniques that will respond to the needs of AFWAL managers, achieve successful implementation in the organization, and enhance the effectiveness of R&D project evaluation and selection.

General Recommendations

1. Given the respondents' low level of familiarity with formal project selection techniques and Dr. Souder's research results concerning negative-to-positive attitude shifts, the first recommendation is that efforts be made to increase AFWAL management's understanding of the uses of formal R&D project selection techniques, with an emphasis on techniques designed to incorporate qualitative input data, such as checklists, scoring models, and Delphi methods. Management should be advised that a new generation of techniques has evolved which may be more responsive to their needs (46:36).

Informing managers about the potential of these techniques could be accomplished through seminars, through the addition of courses in the Professional Continuation Program on base, or through the individual efforts of AFWAL managers. The literature review contained in this document provides a brief overview of four major categories of R&D project selection techniques. In addition, many of the journals and articles listed in the bibliography offer excellent reviews of the latest R&D project selection techniques.

2. The semi-structured nature of the R&D project selection process may lend itself to applications of computer-based decision support systems technology. In reference to computer-based decision support systems, Gordon Davis and Margrethe Olson note the following:

> The main payoff of computer support is for semi-structured problems, where parts of the analysis can be systematized for the computer, but where the decision maker's insight and judgment are needed to control the process. (5:368)

As such, a second recommendation is that AFWAL management investigate the applicability of computer-based decision support systems as a means of enhancing the R&D project selection and evaluation process.

Recommendations for Further Study

1. Although project selection decisions are made by a "corporate board" at each laboratory, the responsibility for deriving the information used in these decisions is that of the scientists and engineers comprising the "technical teams." It is recommended that these groups be included in any follow-on research efforts. By including a larger number of respondents, it would also allow the investigator to test a larger set of adoption-affecting variables without sacrificing sampling adequacy. However, when expanding the sample group, care must be exercised so that only those who influence the project selection process are chosen.

2. As noted above, the semi-structured nature of the project selection process suggests potential applications for computer-based decision support systems. Research into the informational requirements of R&D managers as they pertain to the project selection process could provide further information on this subject.

3. To increase organizational awareness about the potential of R&D project selection techniques, seminars should be conducted to inform managers of these techniques. Following the seminar, the survey instrument provided in this research effort should be re-administered to evaluate the stability of the adoption-affecting variables set. The continuation of this research effort would be useful in helping to identify a R&D project selection technique that would likely be adopted and used by a laboratory.

4. As noted in the fourth conclusion above, as R&D projects progress from basic research to advanced development, the function of management becomes one of evaluating the effectiveness of an R&D project that addresses an Air Force need, rather than selecting a portfolio of projects. Therefore, an investigation of R&D project evaluation techniques which are applicable to mission-oriented agencies may encourage the Air Force manager to adopt a formal R&D project selection technique.

Appendix A: R&D Project Selection Survey

DEPARTMENT OF THE AIR FORCE
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES (AFSC)
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433-6523

16 MAY 1988

REPLY TO
ATTN OF: CC

SUBJECT: R&D Project Selection Survey

TO: Distribution

1. The attached survey will be used to investigate the R&D project selection and resource allocation process here at the Air Force Wright Aeronautical Laboratories. This information is being collected by a graduate student at the Air Force Institute of Technology. I have been briefed as to the nature of this research, and request that you take a few minutes to participate in this survey. I have been assured that all responses will be strictly confidential.

2. The nature of this research requires that our top level managers respond to these questions. It is requested that you do not delegate this survey to your staff.

3. In addition to responding to the survey, some of you may be asked to participate in a short interview. I also ask that you comply with this request if at all possible. Any questions concerning the attached survey should be addressed to the researcher, Captain Jon Congdon, at (513) 236-4645.

James M. [illegible]on
Colonel, USAF
Commander

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R&D Project Selection Survey

UNITED STATES AIR FORCE
SEPTEMBER 18, 1947

R&D Project Selection Survey

Purpose: The purpose of this survey is to investigate the R&D project selection and resource allocation process at the Air Force Wright Aeronautical Laboratories. Several formal techniques have been developed to assist R&D managers in making project selection decisions. This survey is designed to measure your opinions concerning the utility of these techniques.

A formal project selection technique is defined as any model or algorithm used to systematically assign values to individual R&D projects or groups of projects. Formal project selection techniques can be grouped into the following categories: 1) subjective methods; 2) economic techniques; 3) risk analysis techniques; and 4) math programming models. A list of project selection techniques appears in questions 1 through 15 of this survey.

Confidentiality: Your responses to this survey will be strictly confidential.

Survey Responses: None of the survey questions are intended for you to look up any information. Only your opinions are sought. After carefully reading the questions, it is suggested that you respond to them quickly. If you would like to make any comments, please feel free to mark them directly on the survey.

After completing this survey, please place it in the return envelope provided and mail it promptly. Your response is essential to the success of this research effort. If you have any questions or you would like to obtain a copy of the results, please contact me at the following address:

Captain Jon Congdon
AFIT/LSG (GSM88S)
Wright-Patterson AFB, OH 45433
Office Phone: (513) 255-6569

THANK YOU FOR YOUR TIME AND COOPERATION.

Part I

The following is a list of formal project selection techniques. If you are familiar with the technique, please place an "X" in the appropriate column. If you also use the technique regularly in your project selection process, please mark the appropriate column. If you are not familiar with the technique, please do not mark either column.

	Technique	Familiar With	Use Regularly
1.	Q-Sort	________	________
2.	Checklists	________	________
3.	Scoring Models	________	________
4.	Delphi	________	________
5.	Cost/Benefit Ratios	________	________
6.	Payback Period	________	________
7.	Net Present Value/ Internal Rate of Return	________	________
8.	Portfolio Models	________	________
9.	Risk Analysis (Monte Carlo Simulation)	________	________
10.	Decision Analysis/ Decision Trees	________	________
11.	Linear Programming	________	________
12.	Integer Programming	________	________
13.	Nonlinear Programming	________	________
14.	Dynamic Programming	________	________
15.	Goal Programming	________	________
16.	Others? Please list below.		
	____________________	________	________
	____________________	________	________

For the following questions, please place an "X" inside the box that most closely matches your opinion. The use of the term "formal project selection techniques" refers to techniques such as those listed in questions 1 through 16.

17. How would you assess the amount of influence that you have on your organization's R&D project selection and resource allocation process?

Very strong influence — Strong influence — Some influence — Little influence — No influence

1	2	3	4	5	6	7

18. How would you assess the adequacy of the manner in which your division reviews and evaluates potential R&D projects?

Could be improved a great deal — Could be improved somewhat — Uncertain — Probably could not be improved — Could not be improved

1	2	3	4	5	6	7

19. How would you assess the potential worth, to you personally, of a technique which would be designed to assist you in measuring the comparative value of potential R&D projects?

Extremely beneficial — Somewhat beneficial — No benefit or uncertain — Somewhat detrimental — Extremely detrimental

1	2	3	4	5	6	7

20. How would you assess the potential worth, <u>to those people with whom you work</u>, of a technique which would be designed to assist them in measuring the comparative value of potential R&D projects?

Extremely beneficial		Somewhat beneficial	No benefit or uncertain	Somewhat detrimental		Extremely detrimental
1	2	3	4	5	6	7

21. How important, <u>to you personally</u>, would you consider a decision to use a formal project selection technique on <u>all</u> your R&D projects?

Very important to you		Somewhat important to you	Neither important nor unimportant	Somewhat unimportant to you		Very unimportant to you
1	2	3	4	5	6	7

22. If such a decision were to be made what would you recommend?

Definitely should use		Probably should use	Uncertain	Probably should not use		Definitely should not use
1	2	3	4	5	6	7

23. How important, <u>to you personally</u>, would you consider a decision to use a formal project selection technique on <u>at least 50 percent</u> of your R&D projects?

Very important to you		Somewhat important to you	Neither important nor unimportant	Somewhat unimportant to you		Very unimportant to you
1	2	3	4	5	6	7

24. If such a decision were to be made, what would you recommend?

Definitely should use		Probably should use		Uncertain		Probably should not use		Definitely should not use

1	2	3	4	5	6	7

25. Do you feel it is likely that a formal project selection technique could be developed which would be useful to you during your project selection and resource allocation process?

Very Likely	Likely	Uncertain	Unlikely	Very Unlikely

1	2	3	4	5	6	7

26. To what extent do you feel "pressure" from <u>outside</u> AFWAL to quantitatively justify your R&D expenditures?

Extreme pressure	Significant pressure	Some pressure	Little pressure	No pressure

1	2	3	4	5	6	7

27. To what extent do you feel "pressure" from <u>within</u> AFWAL to quantitatively justify your R&D expenditures?

Extreme pressure	Significant pressure	Some pressure	Little pressure	No pressure

1	2	3	4	5	6	7

28. In the space below, please describe any positive or negative experiences you've had when using, or attempting to use, a formal project selection technique.

Part II

Each item in this portion of the survey consists of a statement with which you are asked to agree or disagree. Using the scale shown below, please indicate the extent to which you agree or disagree with each statement. Place a number which corresponds to your opinion in the space provided. Please indicate your opinion even though you may not feel strongly about the statement, or do not feel well informed. Only your initial <u>perceptions</u> are sought. Please try to avoid marking a "3" (Cannot agree or disagree) if possible.

Strongly agree	Tend to agree	Can't agree or disagree	Tend to disagree	Strongly disagree
1	2	3	4	5

Using the scale shown above, please place a number in the space provided which corresponds to your opinion about each statement.

_______ 29. I am, in general, very satisfied with the manner in which projects and tasks are reviewed and evaluated in our division.

_______ 30. The need for a formal project selection technique is not great relative to other changes that could be made in our laboratory's project review and budget allocation process.

_______ 31. My assessment of particular projects or tasks is not likely to change as a result of using a formal project selection technique.

_______ 32. A formal project selection technique would help to make my budget recommendations more compatible with those of my <u>superiors</u>.

_______ 33. A formal project selection technique would help to make my budget recommendations more compatible with those of my <u>research staff</u>.

_______ 34. A formal project selection technique is likely to increase the confidence I have in my budget recommendations.

Strongly agree	Tend to agree	Can't agree or disagree	Tend to disagree	Strongly disagree
1	2	3	4	5

Using the scale shown above, please place a number in the space provided which corresponds to your opinion about each statement.

_______ 35. A formal project selection technique will affect the type of information exchanged when I review and evaluate the projects and tasks in my division/branch.

_______ 36. A formal project selection technique will affect the amount of information exchanged when I review and evaluate the projects and tasks in my division/branch.

_______ 37. The manner in which we review and evaluate projects and tasks in our division does not lend itself to the use of a formal project selection technique.

_______ 38. Formal project selection techniques are, in general, difficult to use and understand.

_______ 39. The information generated by a formal project selection technique cannot be easily communicated to others.

_______ 40. My use of a formal project selection technique is likely to enhance the worth of my budget recommendations.

_______ 41. My use of a formal project selection technique is likely to be considered, by my immediate superiors, as having enhanced the worth of my budget recommendations.

_______ 42. My use of a formal project selection technique is likely to be considered, by my research staff, as having enhanced the worth of my budget recommendations.

_______ 43. More relevant information is likely to be exchanged in my division/branch if I use a formal project selection technique.

Strongly agree	Tend to agree	Can't agree or disagree	Tend to disagree	Strongly disagree
1	2	3	4	5

Using the scale shown above, please place a number in the space provided which corresponds to your opinion about each statement.

________ 44. A formal project selection technique is likely to help identify critical or sensitive aspects of my projects or tasks.

________ 45. My use of a formal project selection technique is likely to increase the overall effectiveness of reviewing and evaluating our division's projects and tasks.

________ 46. The <u>output data</u> that would be generated by a formal project selection technique could not adequately meet my need for such data.

________ 47. I have some reservation about the way in which formal project selection techniques combine or manipulate the input data.

________ 48. I would find it extremely difficult to obtain the input data necessary to use a formal project selection technique.

________ 49. The need for a formal project selection technique is very much increased when funds are scarce.

________ 50. I would recommend that a formal project selection technique be used on <u>all</u> of the projects or tasks in my division.

________ 51. I would recommend that a formal project selection technique be used on <u>at least 50 percent</u> of the projects or tasks in my division.

________ 52. The process by which most formal project selection techniques generate their output data could easily be explained to my colleagues.

Strongly agree	Tend to agree	Can't agree or disagree	Tend to disagree	Strongly disagree
1	2	3	4	5

Using the scale shown above, please place a number in the space provided which corresponds to your opinion about each statement.

_______ 53. I personally feel that R&D project selection decisions which are based on experience and expertise will yield better results than decisions made with the use of a formal project selection technique.

_______ 54. The output data generated by a formal project selection technique could be easily interpreted by laboratory decision makers.

_______ 55. It is likely that a formal project selection technique will provide common outputs that could be easily understood by all laboratory decision makers.

_______ 56. The mathematics involved in most formal project selection techniques are more complicated than is necessary for our project selection process.

_______ 57. The input data for most project selection techniques is difficult to generate due to the uncertainties associated with technological developments.

_______ 58. When I make R&D project selection decisions, I prefer to use a structured, quantifiable process.

Part III

59. What is your sex? (Circle one)   A) Male   B) Female

60. What is your age? (Circle one)

    A) 20-25 B) 26-30 C) 31-35

    D) 36-40 E) 41-45 F) 46-50

    G) 51-55 H) 56 +

61. Please print your military rank or civilian grade. ______

62. Which AFWAL organization are you associated with? (Circle one)

    A) Avionics Laboratory
    B) Flight Dynamics Laboratory
    C) Material Laboratory
    D) Aero Propulsion Laboratory
    E) AFWAL Chief of Staff Section

63. What is the highest educational level you have obtained? (Circle one)

    A) High School Diploma
    B) Associate's Degree
    C) Bachelor's Degree
    D) Master's Degree
    E) Ph.D.

64. What were your major fields of study in the degrees you've obtained?

    A) Associate's Degree ____________________
    B) Bachelor's Degree ____________________
    C) Master's Degree ____________________
    D) Ph.D. ____________________

65. Have you ever taken a course, or attended a seminar in either management science or operations research techniques? (Circle one)

    A) Yes   B) No

66. Would you be willing to attend a course or seminar on formal R&D project selection techniques? (Circle one)

A) Yes B) No

67. Have you ever taken a course or seminar in R&D or laboratory management? (Circle one)

A) Yes B) No

68. What is the approximate size of the budget you are responsible for?

$ ________________.

69. What is your estimate of the percentage of your division's budget dedicated to in-house research versus contracted research?

In-house % _____ Contracted % _____ (Total 100%)

70. What is your estimate of the percentage of your budget that is dedicated to discretionary research efforts which are chosen by your division for their potential value to future Air Force weapons systems, as opposed to research efforts which are specifically requested by an Air Force system program office (SPO) or another outside organization to support a particular weapons system?

Discretionary research chosen by you or your division % _____

Research specifically requested by a SPO or outside organization % _____ (Total 100%)

THE END

THANK YOU FOR TAKING THE TIME TO COMPLETE THIS SURVEY
YOUR COOPERATION IS GREATLY APPRECIATED

Appendix B: Responses to Survey Question 28

1. I have used both Delphi and Decision Trees. The largest problem is trying to achieve a process that is applicable across the board. Since I'm in the Avionics Lab, and since our diversity is so great, it is difficult to prioritize one generic technology against another. As things become more specific, it becomes easier to say which degree of specificity should be ranked higher.

2. The difficulty lies in having a model flexible enough to use on a variety of programs. R&D programs tend to vary greatly in risk (cost and technology), payback, direct application to current systems, etc..

3. It is difficult to substitute some system of numbers for judgment. In fact, somewhere in a numbers-assigning process, one must exercise judgement. Managers use favorable numbers to justify what they've already decided to do, or ignore unfavorable numbers and go ahead with what they've already decided to do.

4. We have a formal project selection technique which we have used and found to be quite effective for many years.

5. Vision. One must have a vision for R&D work, and must be willing and able to fund and support that vision. Formal project selection techniques can be useful, but never as an absolute or single decision process - use it as a tool. It is very important to get folks to use their minds, their vision, and their judgment about the potential of projects, the plan for accomplishing their projects, and the resources applied (including the leader and the timing). Obviously such factors should go into a project selection technique and thus we should use it. However, one must still be willing and able to use that as an input, and can't depend on a subordinate group to do all the thinking or to fill in the blanks by rote. You can't have a useful technique that does not put a premium on experience and expertise.

6. I designed an off-site where we were going to quantify "cutting edge technologies" using a "cross-impact matrix" (after Bennis & Manus), and a voting scheme. Results were accumulated, and would have been used to decide what programs to fund and not to fund. When it was discovered what the results of the voting would do - that is, potentially kill "gold watches" - the process was abandoned.

7. They are typically oversold in terms of their capability. The informal process usually provides answers that are accurate to within 90-95% of more formal processes.

8. The Delphi process is useful to focus on similarities and differences of opinion.

9. Have never used a formal project selection technique.

10. It is very difficult to communicate to higher management. Very hard to break away from the influence of senior civilian and military managers who feel their experience is sufficient to make judgments.

11. Formal project selection processes are used now with considerable success. The process is not computer automated; it is not a by-the-numbers algorithm, and it should not be, though it could use some of these elements.

12. We have an excellent process, developed over a period of many years, for the planning, prioritization, and selection of our programs. To impose a new, mandatory process would be very counterproductive. We do not need more rigidity, more accounting, more process. We need more work, more time to do it, and for people at all levels to be personally accountable for their results, not their plans or their promises.

13. Quantifying payoffs, working to AF needs, etc., is a way of life to the technology community. Formal processes (techniques) in my experience have not survived because they attempt to normalize the vision of the technologist. The strength of the technology base is the in-depth technical knowledge, creativity, and innovations of the scientists and engineers, coupled with their understanding and perception of the current and future military work in their technical area. Technology push vs. requirements pull, in-house vs. contract, facility upgrades, people, etc., are all parts of the investment strategy that have to be addressed. The use of selection techniques for exploratory development (6.2) and basic research (6.1), is of limited value while for advanced development (6.3) and beyond, the value should increase. My experience suggests that the formal selection techniques normally suffer from processing very subjective inputs to output quantified decision and priority data. Using and fine tuning a technique over a long time period (years) may result in a useful tool. The success of future project selection techniques applied to technology could benefit from an AI (Artificial Intelligence) based approach using the decision process that technologists go through in developing and defining their own technology programs.

14. In the past, AFSC attempted to standardize and formalize a process of rating bidder proposals to do R&D programs. It had the acronym TORQUE. It was a disaster, and was left to die without a formal cancellation. I think any formal technique of rating anything is bad!

15. The time it usually takes to do mathematical computations is usually too long.

16. A list of criteria (weighted) has been used as a template on various occasions. The criteria have varied based on the exercise. Near term/far term comparisons were use in the selection process. Absolute, strict use was "disturbing" because some programs that we knew "should" be done didn't fit the "template."

17. The Materials Laboratory has a detailed budget process based on "focal points." This process does not fit your formal technique, but is very productive. AFWAL uses a formal technique for their POM submission. It is of some value, however, you still need a great deal of judgment in such a process.

18. Any project selection criteria must be based on a strong set of requirements (i.e. technical, financial, needs of the AF).

19. Project selection is dependent on many criteria, few of which can be quantified. Previous experience has shown that various selection techniques lead to demonstrably wrong decisions. Also, the worth of certain technologies varies through the project lifetime. It is difficult to apply selection methodologies which have been devised for other types of projects.

20. Past experiences have shown that for 6.1 and 6.2 endeavors, formalized project selection techniques provided little, if any, added value to the final decision process. Rather, sound technological trending, based on experienced scientific and engineering inputs, proves the primary basis for project selection.

21. Past attempts at R&D project selection (such as TORQUE or RDE) suffer from the same problem. They do not evaluate a project in the context of its application. Rather, the assumption seems to be that an individual program can be evaluated as an isolated entity. This cannot work because the value of a specific technological contribution lies in its marginal contribution to the next level of aggregation or integration compared to other options. This requires dynamic programming and hierarchical modelling, and is rather labor intensive. At the HQ AFWAL level, we have used Delphi to rank order biennial POM cost/benefit packages for over ten years. It works extremely well.

Appendix C: Interview Questions

1. Name:

2. Rank/Grade:

3. Organization:

4. How does your organization evaluate and select research projects during your resource allocation process? Does your organization utilize a standardized process? If so, does this process rely on the use of formal project selection techniques?

5. Who participates in this process? What roles do they have?

6. Does this process differ depending on the type of research being conducted (e.g. 6.1, 6.2, 6.3)? If so, how?

7. Do you feel a formal project selection process would either enhance or diminish the effectiveness of your project selection process? Please explain.

8. How do budget cutbacks affect your project selection process?

9. Do you feel any pressure to quantitatively justify your R&D project selections? Please explain.

10. What characteristics do you feel a useful project selection process should have?

11. What criteria do you feel are important to consider when reviewing R&D projects?

12. What comments would you like to add concerning the R&D project selection process or any other aspect of this research?

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Vita

Captain Jonathan D. Congdon [redacted] He graduated from Keene High School in 1978, and received the degree of Bachelor of Science in Mechanical Engineering from the University of New Hampshire in May, 1983. Upon graduation, Captain Congdon attended USAF Officer Training School at Lackland Air Force Base, Texas, and was commissioned in September 1983. He was then assigned to Headquarters Space Division, Los Angeles Air Force Station, California. During his assignment to Space Division, he served as an engineer in the Advanced Launch Systems Program Office. In May, 1987 he entered the School of Systems and Logistics at the Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio. [redacted]

Permanent Address: [redacted]

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Jonathan D. Congdon, B.S., Capt, USAF

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Thesis Advisor: Major Thomas Triscari
Associate Professor of Systems Management
Department of Systems Acquisition Management

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WILLIAM A. MAUER 17 Oct 88
Associate Dean
School of Systems and Logistics
Air Force Institute of Technology (AU)
Wright-Patterson AFB OH 45433

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Although several techniques have been developed to enhance R&D project selection decision-making in research laboratories, they have not been widely accepted by management. This research examined three aspects relating to the implementation of R&D project selection techniques at the Air Force Wright Aeronautical Laboratories (AFWAL). It examined 1) the methods used by managers to make R&D project selection decisions; 2) the attitudes and perceptions of managers toward the utility of R&D project selection techniques; and 3) the specific factors affecting the adoption of these techniques by R&D managers.

Findings showed that R&D project selection techniques play a minor role in the project selection process, and that managers are generally unfamiliar with these techniques. Instead, project selection decisions are often made by top-level laboratory managers through a review process. Findings also showed that the project selection process at AFWAL is primarily driven by "requirements pull" as opposed to "technology push."

Factor analysis was used to identify an initial set of variables which affect management's willingness to adopt R&D project selection techniques. These variables were factored into two groups relating to 1) the impact of formal project selection techniques on organizational decision-making; and 2) the characteristics of the project selection techniques themselves. The results showed that the respondents possessed negative perceptions toward the utility of these techniques.

Previous research efforts have shown that negative-to-positive attitude shifts have occurred when respondents were provided with education and training in the use of these techniques. Consequently, it was recommended that managers be provided with training to increase their understanding of these techniques. A suggestion was also made to examine the applicability of computer-based decision support systems to the R&D project evaluation and selection process.